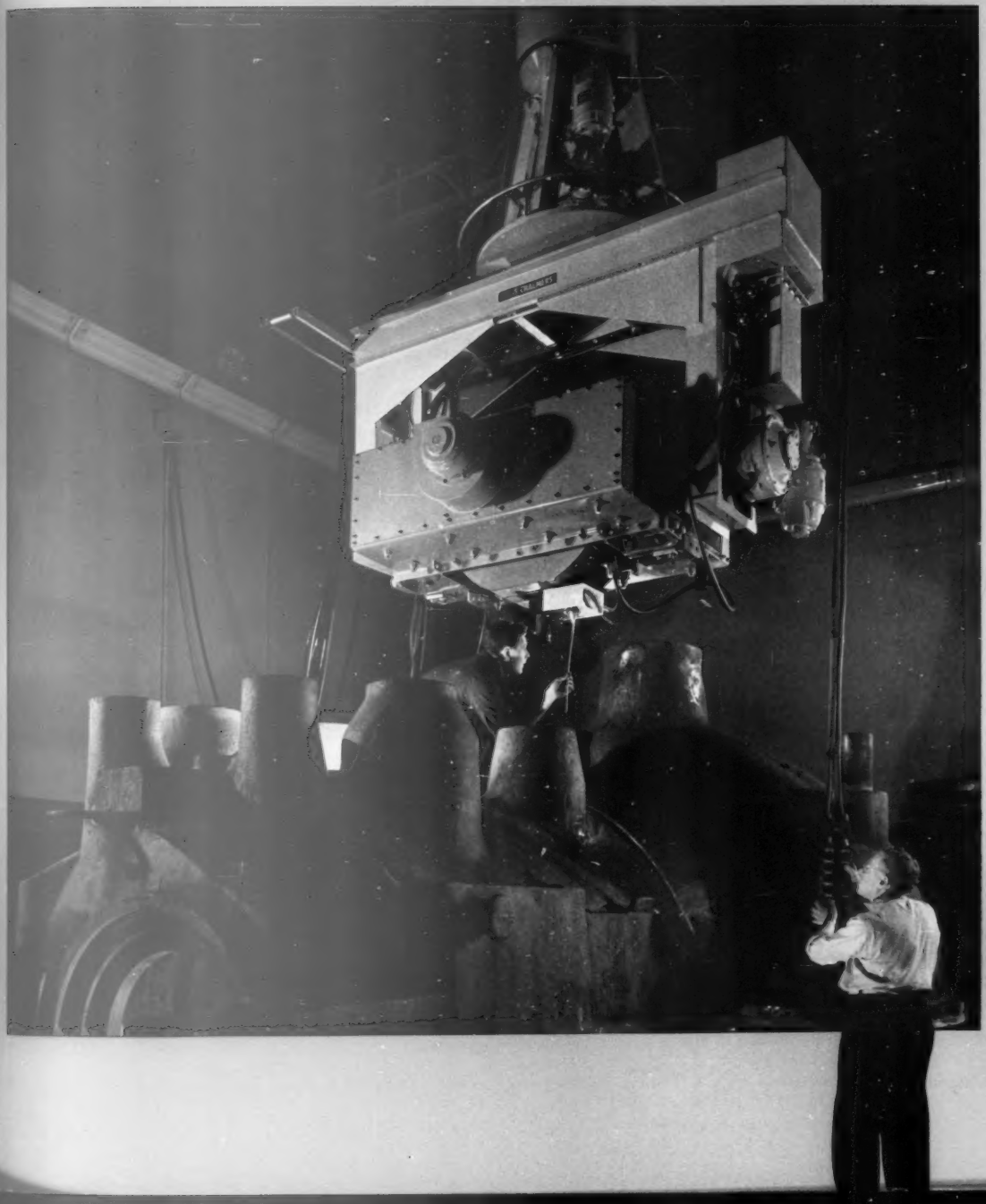
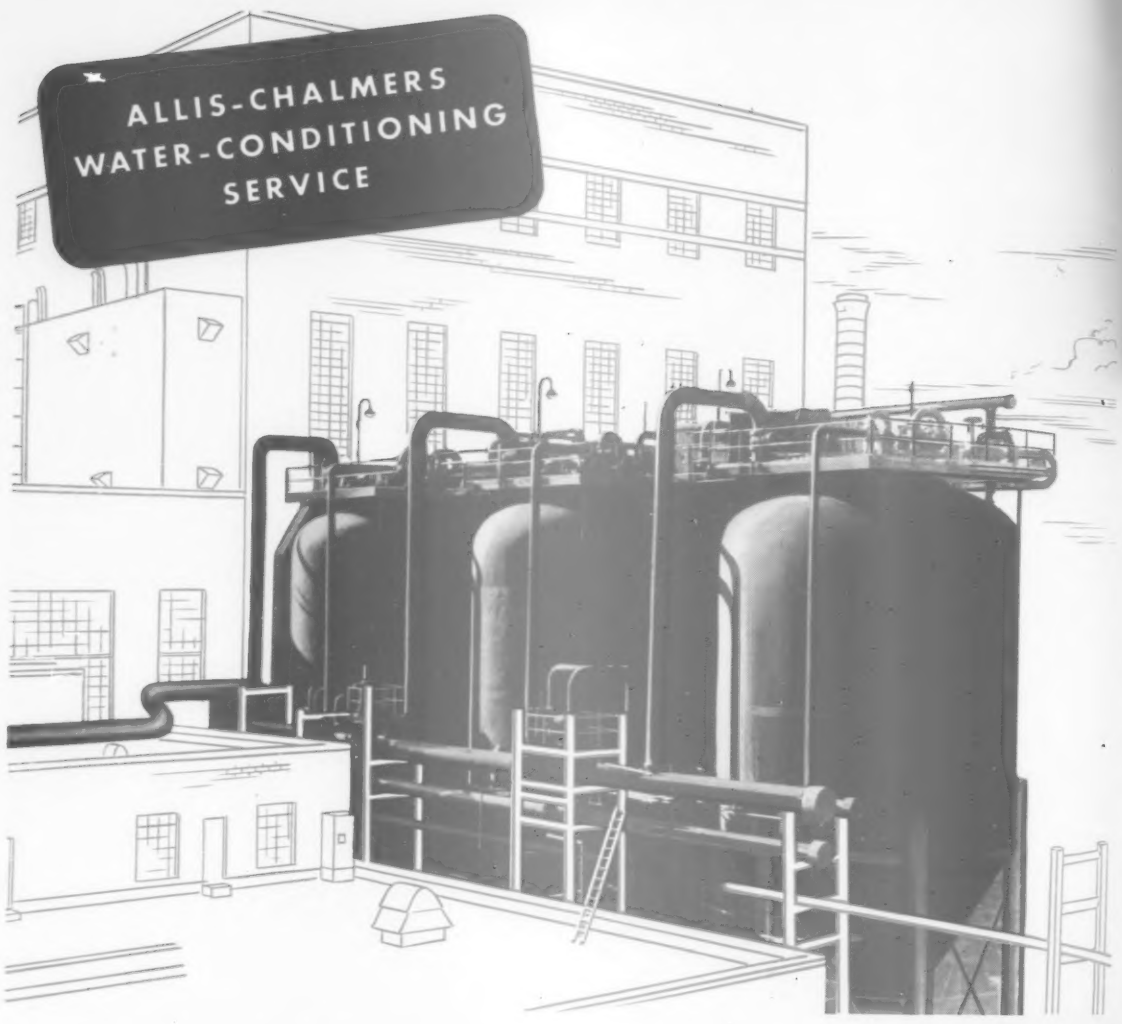
# ALLIS-CHALMERS Electrical REVIEW

1ST QUARTER 1953



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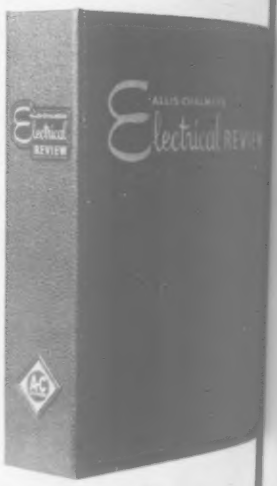


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# Curing Intricate Cores With Dielectric Heat

**LARGEST OF 95** cores for a close tolerance, intricately cored casting, this core weighs nearly 400 pounds, is lifted from the dryer by a crane.

by **CARL LOPER**
Electronics Section
Allis-Chalmers Mfg. Co.

***Cores on metal plates are cured in the dielectric field of this electronic dryer which has added radiant heating elements.***

THE ART OF FOUNDING or casting metals into useful objects is estimated to be some 6,000 years old. The first casting made in America, the famous Saugas iron pot, was poured in 1642. From that time until the opening of World War II the foundry industry had a slow but steady growth. Since then, however, the challenge of close tolerances, increasing quality, and sufficient quantity to meet the needs of both industry and defense has resulted in many radical changes in core and molding practice.

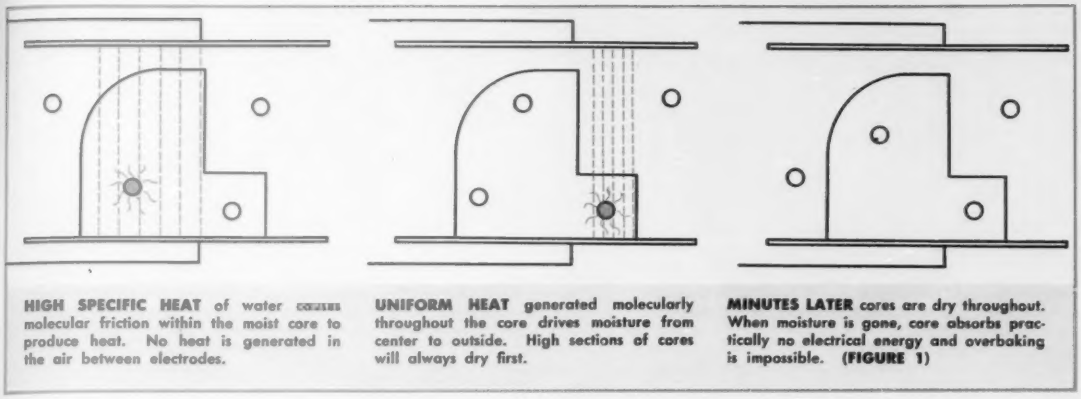
Undoubtedly one of the most startling changes has been the application of dielectric heat in the core room for baking or curing the cores which form the interior surfaces of a casting.

In conventional core room practice it is customary to prepare a core from clean, comparatively clay-free sand, cereal, oil binders, and water. This mixture, formed into the desired core shape by any one of several different methods, is placed on a metal or *Transite* plate and baked in an oven at 450 to 500 F. The ovens are usually gas or oil-fired, and baking times may vary from 30 minutes to overnight periods, depending upon the size of the core.

## Curing not always uniform

Just as in baking a cake in a household oven, it is necessary that the oven walls, racks, plates supporting the cores — everything within the oven — be heated to the desired temperature. In baking a core, water is removed through heat transfer by conduction from grain to grain, progressively from the outside surface to the center. After the water is removed, the oil binders polymerize into a hard mass, thoroughly bonding the sand grains into a core. After removal from the oven and a time lapse for sufficient cooling, these cores can be easily handled.

Normally, it is estimated that 45 minutes to one hour must be allowed for each inch of cross sectional area when baking cores by this method. It is quite obvious that if the sectional area of a core varies, there is danger of overbaking or burning the thinner sections while waiting for the heavier sections to bake out completely. This overbaking or burning can result in scrapped cores or scrapped castings because of reduced core strength. Conversely, if the core remains in the oven only long enough to bake



**HIGH SPECIFIC HEAT** of water causes molecular friction within the moist core to produce heat. No heat is generated in the air between electrodes.

**UNIFORM HEAT** generated molecularly throughout the core drives moisture from center to outside. High sections of cores will always dry first.

**MINUTES LATER** cores are dry throughout. When moisture is gone, core absorbs practically no electrical energy and overbaking is impossible. **(FIGURE 1)**

out the thinner sections, the heavier sections will be underbaked and have soft or incompletely baked centers. When molten metal is poured around it, the center resumes baking. Moisture attempts to escape, and burning organic material within the core causes excessive gas. Many scrapped castings due to blows, scales, and pinholes result.

## New method is faster, results are uniform

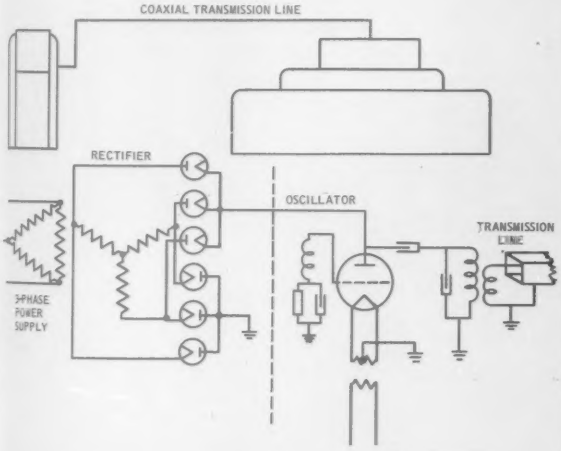
Dielectric heat eliminated many disadvantages found in conventional methods of baking cores. This new baking method depends upon molecular friction in a rapidly reversing high frequency dielectric field, see Figure 1. The presence of water in the core material causes the temperature of the cores to rise to approximately 230 or 240 F. Water is driven off in the form of steam, and the synthetic resins used as binders are "set up," or cured. As the power absorbed by the core is almost entirely dependent upon the amount of moisture present, as soon as the moisture is removed from a thin section or small core it no longer bakes. This action is comparatively rapid. Curing time is reduced from hours to a matter of minutes.

Using a modified Hartley oscillator circuit, Figure 2, the dielectric core dryer has proved acceptable to the foundry industry in numerous applications throughout the country. One recent installation indicates the extent to which dielectric heating has improved the art of casting metals.

A leading Midwest aluminum foundry, confronted with a large scale program to supply the rear main frame casting for a jet engine, installed a specifically engineered dielectric core dryer that incorporates both dielectric and radiant heat.

## Problems encountered

In order to maintain close tolerances in an intricately cored casting, it has become the accepted practice to use com-




**A MODIFIED HARTLEY OSCILLATOR,** diagrammed above, requires 3-phase, 60-cycle, 180-ampere, 460-volt input. Full-load power output to electrodes is rated 60 kw, with 70 kw available for maximum operation. **(FIGURE 2)**

**THIS INTRICATE CASTING,** weighing over 190 lb and shown from the drag end, is for the rear main frame of a jet aircraft engine. **(FIGURE 3)**

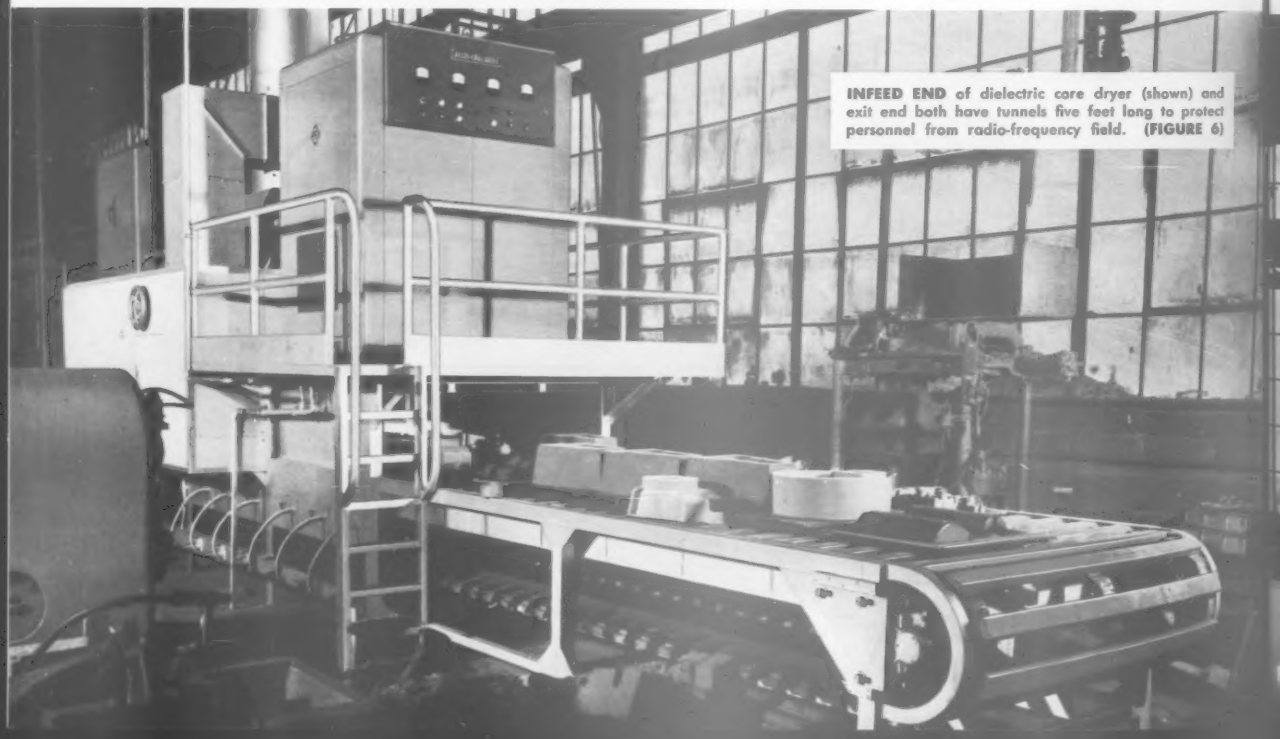
**ACCURACY OF CORE** construction and varying wall thickness are shown by this cope view of the same casting pictured in the previous illustration. **(FIGURE 4)**

**A COMPLETE SET OF CORES** is cured every 40 minutes and is nearly ready for assembly when taken from the dryer. Core assemblers keep check lists handy for frequent reference. **(FIGURE 5)**

plete core-mold assemblies in which the entire mass of sand supporting the casting is made of cores. In this manner desired accuracies of wall section thickness are easier to obtain. Figures 3 and 4 show the cope and drag views of the J-47 jet engine rear main frame casting and indicate the numerous intricately cored sections. Specifications require that this casting be held to $\frac{1}{32}$ in. tolerance.

The complete core-mold assembly consists of some 95 cores which range in weight from 2 oz to 394 lb each. The core-mold, upon final assembly, weighs over 2100 lb, while the casting itself weighs about 190 lb. As exceptionally close tolerances are required in the finished casting, minimum core handling was necessary to eliminate sagged or damaged cores. In addition, to save time in assembling the finished cores and insure dimensional accuracy in the placement of the cores, the base core was designed with prints to indicate the location of subsequent cores in the assembly. To further insure desired accuracy, it was imperative that the base core remain on the metal plate upon which it was baked for immediate assembly with the other cores.

To eliminate the possibility of one or more operations being neglected, which would result in an expensive casting being scrapped, a casting check sheet was instituted. In practice, all cores for a given assembly are similarly numbered and the casting from that assembly bears the same number. All information on the quality of the cores, placement of chills, assembly of the cores, needed patching, core wash applications, difficulties encountered in assembly, gauge reports on core setting, metal melting, fluxing, and pouring temperatures, pouring time, cleaning room inspection reports, laboratory analysis



**INFEED END** of dielectric core dryer (shown) and exit end both have tunnels five feet long to protect personnel from radio-frequency field. **(FIGURE 6)**

reports, X-ray inspection — all operations up to final shipment of the casting are entered on the check list. Any problems which might arise as the casting is inspected or machined can be traced to the source quickly. Partial assembly of the core-mold is shown in Figure 5, which also indicates the metal plate upon which the core is cured and the check sheet in use for that casting.

## Development of dual heat core dryer

Early applications of dielectric heat in the foundry indicated that the most economical operation and highest production could be obtained by the use of low density materials to support the core during the curing operation. The most commonly used materials have been *Transite* plates, *Marinite* plates, or marine type plywood. To support irregularly shaped cores, several casting resin compounds and putties have been developed which contain the desired dielectric properties.

Curing resin bonded cores on metal plates in a dielectric core dryer had been considered impractical because a chilling action was imparted to the core surface. The chilling resulted in wet or uncured sections of the core where it contacted the plate, a condition corrected only after extended curing periods. To change over to nonmetallic plates for this application would involve considerable expense.

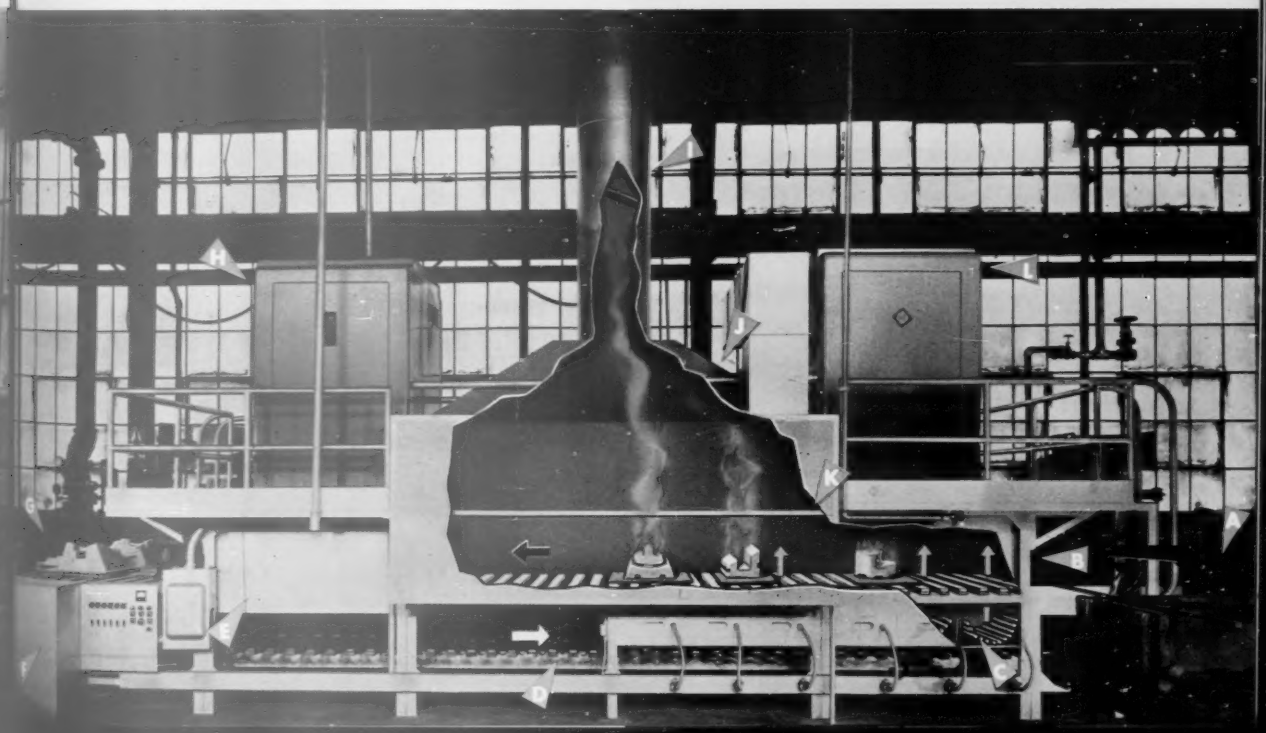
A series of experiments revealed that resin bonded cores could be successfully cured with no appreciable change in the dielectric capacity of the core dryer if the metal plates were preheated to approximately 220 F and if the operation proceeded at such a rate that the cores were cured before the plates cooled below 200 F. These tests resulted in the development of the first dielectric core dryer in which metal plates can be used to support the cores.

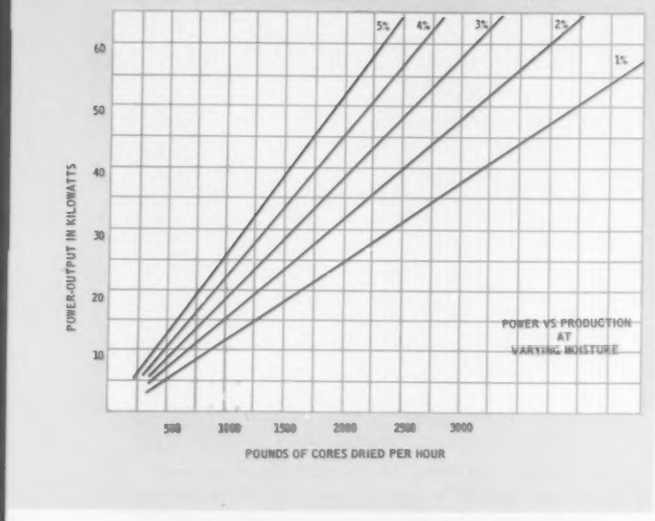
This core dryer has an oven or curing chamber 9 ft wide by 10 ft long. Projecting from each end are infeed and exit tunnels which measure 5 ft long, 5 ft wide, and 18 in. high. They confine radiations from within the oven and protect personnel from the radio-frequency field. Passing through the oven is a variable-speed metal slat-type belt conveyor 40 ft long to carry the cores through the dielectric field. A view of the infeed end of the dielectric core dryer is shown in Figure 6.

To heat the metal plates, standard heating elements are installed below the conveyor belt as shown in Figure 7. They are arranged to direct their heat upwards through the openings in the belt and heat the bottoms of the plates. Three elements are located under the infeed tunnel to preheat the plates, while three others are located below the electrode proper to assist in retaining the heat. These heating elements are rated at 9600 watts each. As heating

A — Infeed Loading Area
B — Infeed Tunnel
C — Radiant Heating Units
D — Motorized Endless Belt
E — Exit End Tunnel
F — Variable Conveyor Drive
G — Core Unloading Area
H — Rectifier Cubicle
I — Dampered Fume Flue
J — Dielectric Oven Hood
K — Adjustable Electrode
L — Oscillator Cubicle

**FIGURE 7**






**POWER CONSUMPTION** and production are dependent upon the amount of moisture in the cores, as shown by these curves marked to indicate percent of moisture present. **(FIGURE 8)**

time varies for different sized plates, it has been found practical to retain an ambient heat in the oven compartment of approximately 200 F. This is done by means of an adjustable damper in the exhaust stack which removes fumes and moisture from the oven.

As the core plates pass over the heating elements, plate temperature increases to plus 212 F at the point where the cores enter the R-F field. While dielectric heat is curing the cores, the additional elements below the electrode assist in retaining the temperatures of the metal plates. Thus the dielectric current is permitted to cure the resin bonded sands with no adverse results from the metal plates.

## The R-F generator

Radio-frequency current for dielectric drying of the cores is supplied by a dielectric heater operating at approximately 15 megacycles. Components of the generator are contained within two cubicles.

This unit requires a 3-phase, 60-cycle, 180-amp, 460-volt line regulated to 10 percent, and operates at a power factor of 0.9. Power input to the unit is approximately 143 kva or 130 kw. Full load power output to the electrode for core drying is rated at 60 kw, even though 70 kw is available for maximum operation.

The alternating current input voltage is transformed to high voltage, changed to direct current by the full-wave mercury vapor rectifier tube section, and then transformed by the heavy duty vacuum oscillator tube circuit into high frequency alternating current. A co-axial transmission line conducts this R-F current into the oven compartment where it is applied to the electrode.

All doors to the generator compartments and oven sections which contain high voltages are interlocked with the oscillator plate power circuit to protect personnel. In addition, relays, plate power limit controls, water temperature, and flow controls protect against normal misuse of the equipment.

## Preparation and curing of cores

A uniform step-by-step procedure from coremaking through the drying and assembly of the core-mold was installed for the handling of the cores for the jet casting.

The general sand formulation consists of:

| | |
|---|---|
| Ottawa Silica Sand | 400 lb |
| Juniata Bank Sand | 150 lb |
| Cereal Flour | 5 lb |
| Resin Binder | 4 lb |
| Catalyst | 1 lb |
| Glycol | 1 qt |
| Release Agent Mixture | 3 qt |
| Water | 1¾ gal |

The ingredients are mixed in a high speed muller. Mixing time with the water and release agent are very critical and must be closely controlled.

Coremaking equipment, which consists of blow machines, jolt roll-over machines and some benchwork equipment, is arranged conveniently close to the infeed conveyor belt of the dielectric core dryer. The completed cores are placed directly onto the conveyor belt to minimize handling of "green" cores. The elimination of several handling operations reduces sagging and distortion and contributes immeasurably to the dimensional accuracy of the finished cores.

Cores to a maximum of 17 in. high can be handled on this dielectric core dryer. The tallest core in this assembly is approximately 9 in. high, while the smallest section will approximate ¾ in. All cores, regardless of size or dryer requirements, are cured at the same time. There is no necessity for frequent adjustments of the electrode to compensate for various core heights. The amount of power drawn from the generator will be proportional to the mass of cores under the electrode at one time. Since the power factor, or ability of the core to absorb power, is much higher when moisture is present within the core, the equipment automatically protects the smaller cores from over-curing as shown by Figure 8.

As the cores on preheated metal plates enter under the electrode, the moisture within the cores causes an increase in the power the generator supplies because the capacity of the dielectric field is changed. This results in an absorption of power by the wet cores, which continues until the cores have dried out. As the cores dry out, the moisture content is reduced and the power consumed decreases to minimum. This automatic power loading feature, inherent in the electrical characteristics of sand cores, offers great advantages over the conventional high temperature baking practice. In conventional baking practice it is necessary to keep the baking zone at definite temperatures at all times, resulting in a constant use of power to replace lost heat. In dielectric core practice power is only consumed proportional to the mass and water content of the cores.

The ability to handle all the various sized cores in this assembly without fear of overbaking or burning thin sections permits the progressive assembly of each core-mold. Storage for a large number of small cores, customary in conventional practice, is not necessary.

The largest core in this assembly is cured in 10 to 12 minutes total time, while a complete core assembly is

possible every 40 minutes. Several cores weighing in excess of 800 lb are completely cured in 20 to 22 minutes without overbaking thin cross sections of the core. As the speed of the conveyor belt is adjustable through a variable control from 6 in. per minute to 36 in. per minute, the production is dependent only upon the length of time required to dry the largest mass of core passing through at one time. Figures 9 and 10 indicate the variety of cores that are cured simultaneously.

One noteworthy accomplishment has been the elimination of many rods and wires formerly used to support the green cores during handling and curing. As the cores require less handling, many rods were eliminated immediately. Some rods offered an easy path of current conductance because of their placement, causing arcing problems. Due to the strength of the resin bonded sand, many of these rods were eliminated. The comparatively few rods and wires still necessary are placed so that they do not interfere with the dielectric field.

## Core assembly and casting

Cores are removed from the conveyor belt as soon as they emerge from the core dryer. Base cores are placed on skids while still on their metal plates; and the other cores, after numbering, are placed in close proximity to the base core to facilitate assembly. Fins on the baked core, the result of loose pieces in the core boxes, are removed, and any further finishing is performed immediately. Required core washes are applied at once and are dried from the residual heat within the core, which at this point is approximately 200 F. Since the cores are completely cured when removed from the dielectric oven, the core room is free from smoke and fumes commonly associated with conventional oven baking.

To insure a perfect core-mold assembly, the nearly 100 cores must be fitted together with extreme care. Filing and grinding is reduced because the resin bonded cores cured in the dielectric core dryer retain original accuracy to a high degree. In addition to the locating points in the base core used for assembly, several jigs are available to insure accuracy of alignment of the various cores. The casting check sheet is invaluable here in that it insures the correct placement of each core in the assembly.

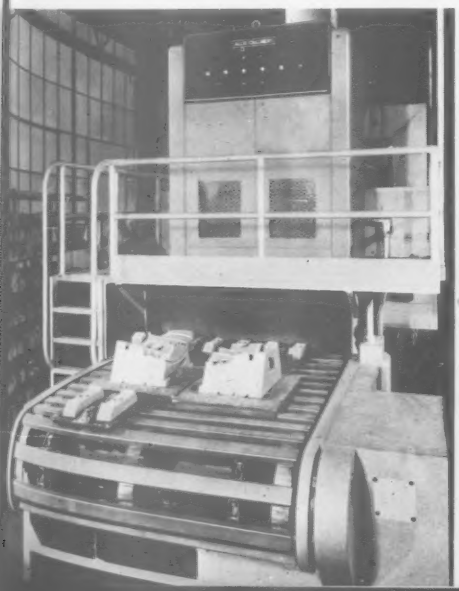
The aluminum alloys used for this casting undergo strict melting, fluxing, and pouring practices to insure that the resultant metal will meet detailed laboratory specifications. All temperatures are controlled through the use of immersion-type thermocouples connected to constantly recording potentiometers. Fluxing procedure is performed within strict temperature ranges. All core-mold assemblies are poured off at approximately the same temperature, and pouring time is uniform.

When the core-molds are poured off, dissociation of the resin binders produces some smoke and fumes. Because of this, core-molds are transported to an outside yard for cooling. After cooling, the core-molds are taken to a shakeout station where sand is stripped from the casting, metal fins are chipped from core joints, and the entire casting is cleaned. Since solidification stresses are apt to be present in such castings, a definite heat treat procedure is followed to relieve any stresses that may exist.

## Castings thoroughly inspected

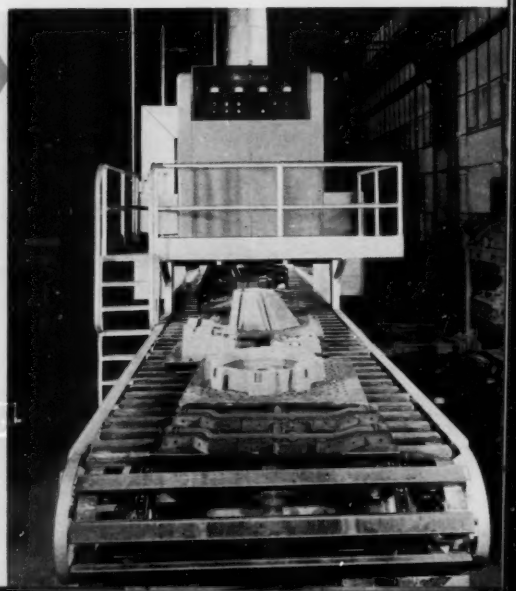
As considerable machining is necessary on the castings to prepare them for operation in jet engine service, each casting is subjected to an exhaustive "target" operation which checks wall thickness and the centers of cored openings, indicates the location of holes to be drilled, indicates the amount of machining necessary on all surfaces, and locates definite points from which the machining operation is to proceed. Following this inspection and preparation, the castings are subjected to a 2½-hour X-ray inspection which includes some 32 exposures to insure against any internal defects. A regular *Dye-check* inspection is made on certain surfaces to reveal the presence of microscopic cracks. A *Zyglo* inspection is also performed on the casting just prior to machining. Regular test bar procedure for mechanical and chemical properties is conducted on each casting in the laboratories.

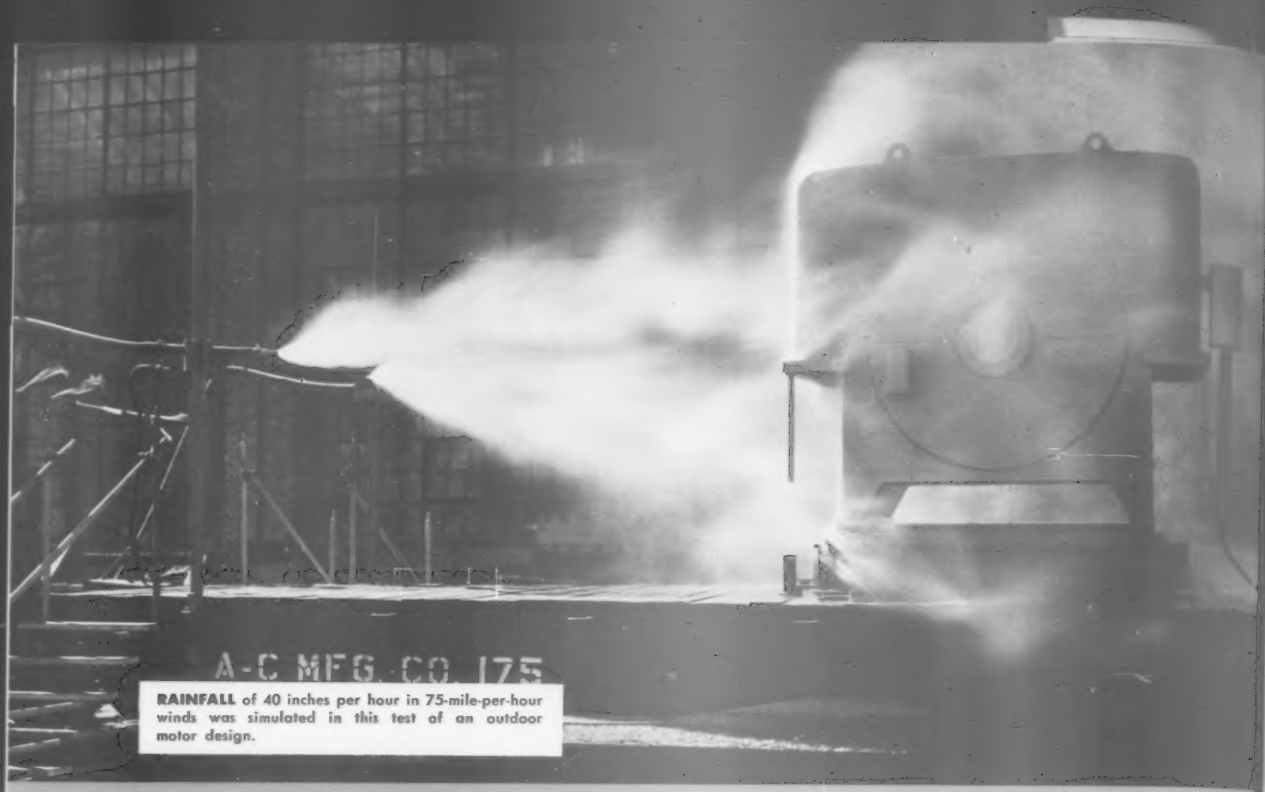
Today's high percentage of acceptable castings is attributable to strict control of procedure at every step of the way and to the controlled curing obtained with the dielectric core dryer.



**THE WIDE VARIETY** of core sizes and shapes cured simultaneously, each on its own metal plate, is indicated by this view of the core dryer infeed end. **(FIGURE 9)**

**CURED CORES** can be removed from exit end by hand if small enough, since the maximum temperature attained in the dielectric heater is only 230 F. **(FIGURE 10)**






**RAINFALL** of 40 inches per hour in 75-mile-per-hour winds was simulated in this test of an outdoor motor design.

# Their Ceiling is the Sky — OUTDOOR MOTORS

by **C. D. LAWTON**
Motor-Generator Section
Allis-Chalmers Mfg. Co.

***As building costs have gone up, motors have donned new dress . . . moved outdoors clad only in factory-built enclosures.***

THE STORY OF CONSTRUCTION and application of outdoor motors is especially interesting at this time because many industries, in present-day programs of expansion, are considering the use of outdoor equipment. Predominant in this field are public utilities and oil and gas industries. Increasing building costs in both materials and labor have accelerated the trend for outdoor equipment location.

The movement began in the South and gradually spread north. Today outdoor motors are operating successfully in climates with winter temperatures as low as 15 to 20 degrees below zero.

The demand for outdoor motor equipment in recent years has resulted in the manufacture of new types of motors to meet the rugged conditions of operation. New developments of successful motors are worked out on a background of experience and a complete understanding of application problems. This background begins many years ago when motors were first used outdoors.

## Outdoor motors grow in size

Operators realized that in outdoor operation motors would be exposed to all types of weather plus dust and dirt. For this reason, the smaller totally-enclosed fan-cooled motors were applied with reasonable assurance that they would operate successfully. Some motors were secondarily ventilated; smaller ones were nonventilated. Other more courageous engineers modified ordinary splash-proof motors for outdoor use by using specially varnish treated windings and screens over the air inlet and discharge openings. As confidence was gained, larger and still larger motors were placed outdoors.

Industry then demanded outdoor motors larger than 300 hp, commonly the maximum rating of totally-enclosed fan-cooled motors. Public utilities began to use motors of 400 to 500 hp of conventional splash-proof design for driving draft fans. As with the smaller motors, the windings were varnish impregnated in a special manner to withstand heavy moisture conditions. But even then, during strong wind-driven rains, the windings would become coated with water. This type of motor had another disadvantage: if windings were covered with deposits of flyash and wet conditions prevailed, insulation failure could result. As a protective measure, motors were equipped with space heaters to keep them warm and dry

during shutdown periods. This was the situation prevailing in the 1930's and early 1940's.

It became apparent that outdoor installations were here to stay. However, better mechanical protection against the elements had to be provided to assure unfailing plant operations, since equipment worth many thousands of dollars was at stake.

## Construction changes as size increases

Soon several new types of construction appeared with no limiting horsepower strings attached to them. These motors were built with totally-enclosed covers; some were self-ventilated, others were forced ventilated by ducts from an external source. Since the outdoor air passed through the ventilating passages, all necessary precautions learned from previous experience with splash-proof motors were incorporated. Because these motors were complicated by ducts, blowers and protective equipment, their use was not widespread.

During World War II many factors hurried the development of large motors that could be installed outdoors. Building costs soared. Longer and bigger oil pipe lines were constructed. Power plants used larger generators, all requiring more horsepower and larger motors. The oil industry particularly wanted explosion-proof motors to operate on pipe lines and in refineries. There were none available at that time, as the common motor designs limited explosion-proof motors to around 400 to 500 hp. In an attempt to meet this need, enclosed motors filled with inert gas kept under pressure made their appearance, but they entailed the nuisance of gas bottles and safety devices.

## Tubes help protect from weather, explosions

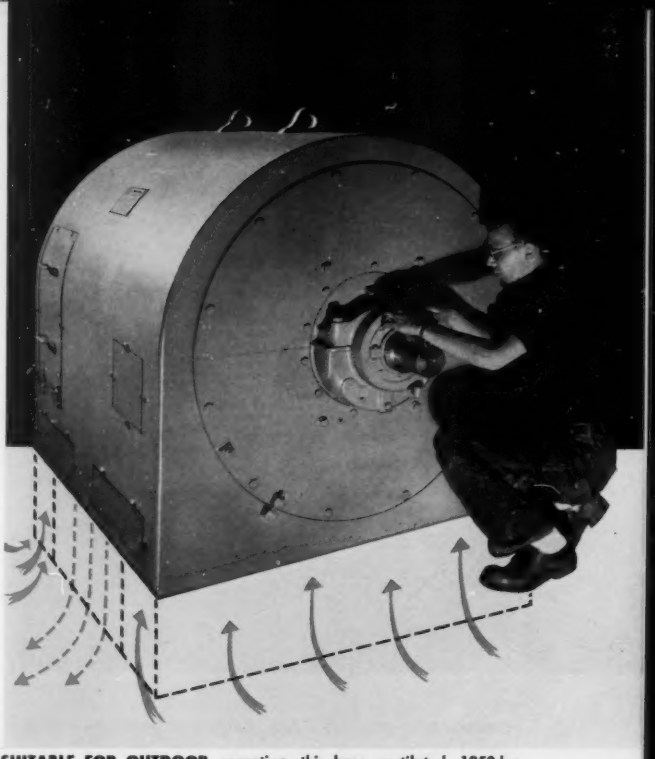
It was about this time that tube-cooled construction was developed and applied to large explosion-proof motors. This simple ventilating system proved to be very efficient. Underwriters' Laboratory tests and subsequent use proved its reliability in explosive atmospheres.

This motor design filled a long felt need for a large unit type motor that was explosion-proof, completely weatherproof and adaptable to outdoor installations. Acceptance was immediate, demand great. Hundreds of them have been built for use in every type of industry. They have been placed both indoors and outdoors.

This motor has been the "ultimate" in outdoor design for these several reasons: outdoor contaminated air does not reach the inside of the motor; its external ventilating system uses straight tube air passages which are easily cleaned when necessary; the periphery of the yoke is uniformly cooled; and cooling tubes may be made of special materials if corrosive atmospheres such as those found in certain chemical processes warrant this step. Thus the active electrical motor parts are completely protected, the motor's useful life is longer, maintenance schedules shorter, and reliability far greater.

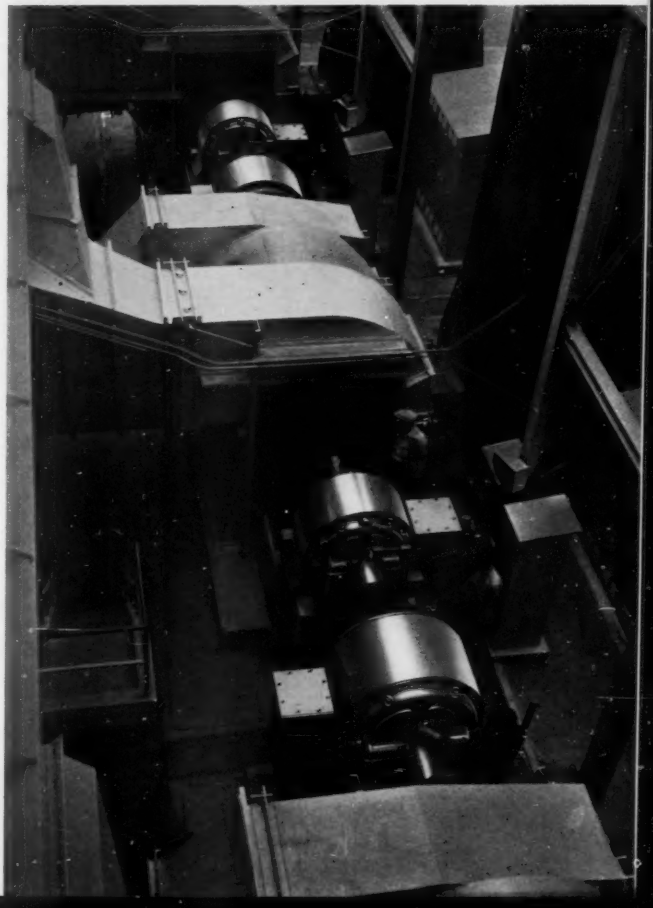
## Seek lower cost construction

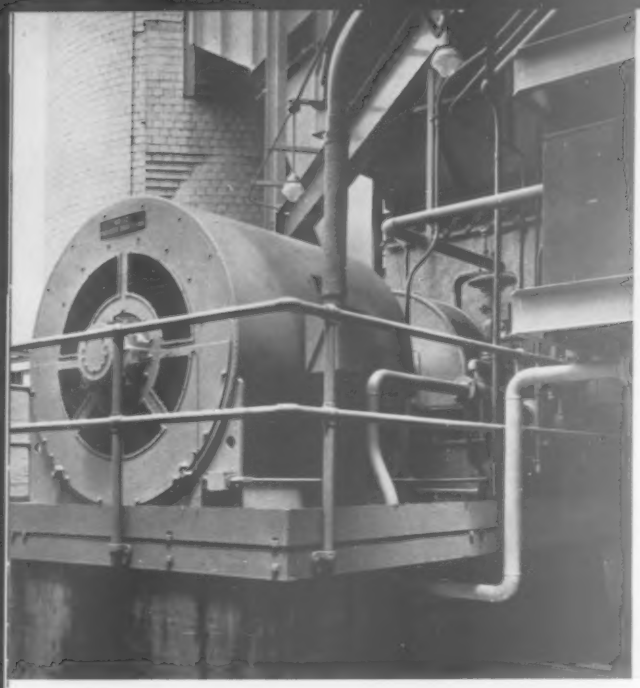
As labor costs continued to rise, equipment costs were affected and industry had to find a means of lowering

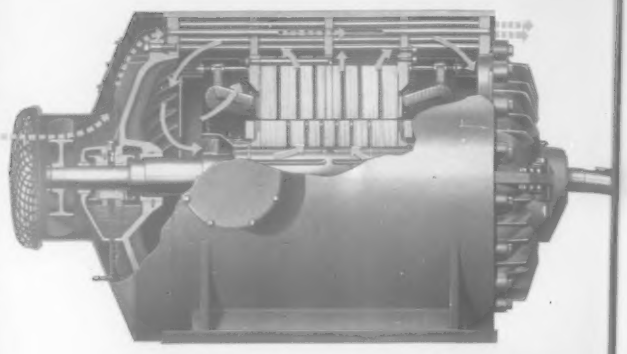


**SUITABLE FOR OUTDOOR** operation, this base ventilated, 1250-hp squirrel-cage motor is designed for pipe-line service. Cooling air is drawn in and exhausted through ducts as indicated.

**EARLY OUTDOOR INSTALLATIONS** utilized conventional splash-proof motors. These 400-hp, 880-rpm splash-proof motors are driving draft fans in a power plant on the west coast.







**AIR-TO-AIR** heat exchanger on this totally-enclosed fan-cooled motor is a nest of tubes around the periphery of the motor. Cooling air is forced through the tubes.

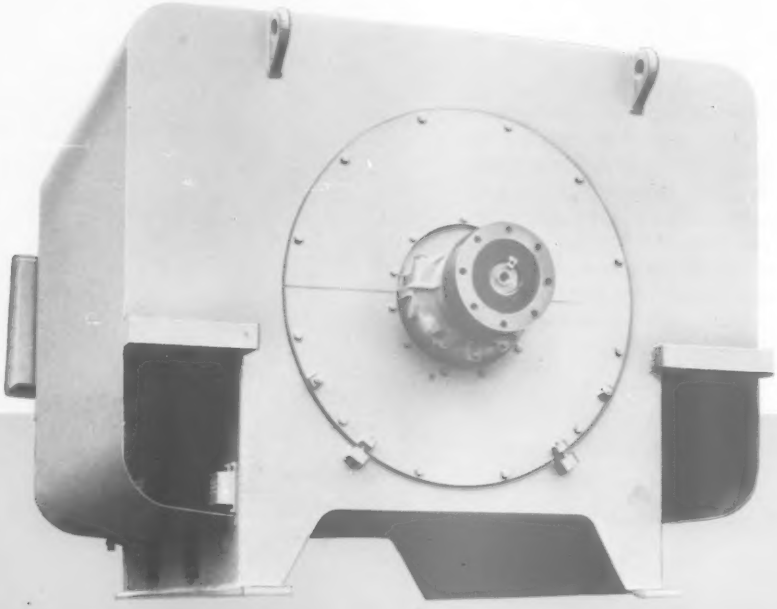
**MORE RECENTLY,** outdoor draft fan drive motors have been of totally-enclosed design like this 1250-hp, 590-rpm, silicone insulated, fan-cooled tube-type cage motor.

construction expense. An analysis of construction costs added further impetus to the use of outdoor locations for motors. This resulted in incident redesign of older types of motor ventilation for specific applications. It also resulted in the development of a new type outdoor motor which might be called a supersplash-proof, but which is termed "weather-protected."

The petroleum and gas industry, particularly the pipeline divisions, needed outdoor motors of the explosion-proof types in large horsepower sizes. Because of the expense of totally-enclosed, fan-cooled, explosion-proof motors, other types were investigated. The forced ventilated motor is one type that has proved satisfactory. Many of these have been installed indoors, but outdoor locations are just as feasible. The motors are totally enclosed, usually with ducts attached to the base for both inlet and discharge ventilating air. Usually several motors are involved and all the ducts for the admission of cool, clean air are run from a common ventilating fan at a remote point. Warm discharged air may be used to heat adjacent buildings if desired. The motor's interior is kept under air pressure so that in effect they are explosion proof.

## Weather-protected motors evolved

The "weather-protected" motor has gone through a period of evolution during recent years, involving among other variations the use of base ventilation. Air inlets below the motors were provided in specially constructed concrete bases so that wind driven rain could not get directly into the motor intake. Filters provided protection against dust and dirt. Air discharge was through deep flared openings at the sides of the yokes. This construction, while



**SIMULATED** weather testing resulted in the addition of air intake protection covers to prevent pressurizing air intakes in high winds.

effective, was costly because of special foundations. These special foundations also increased the mounting height of the equipment, causing further problems.

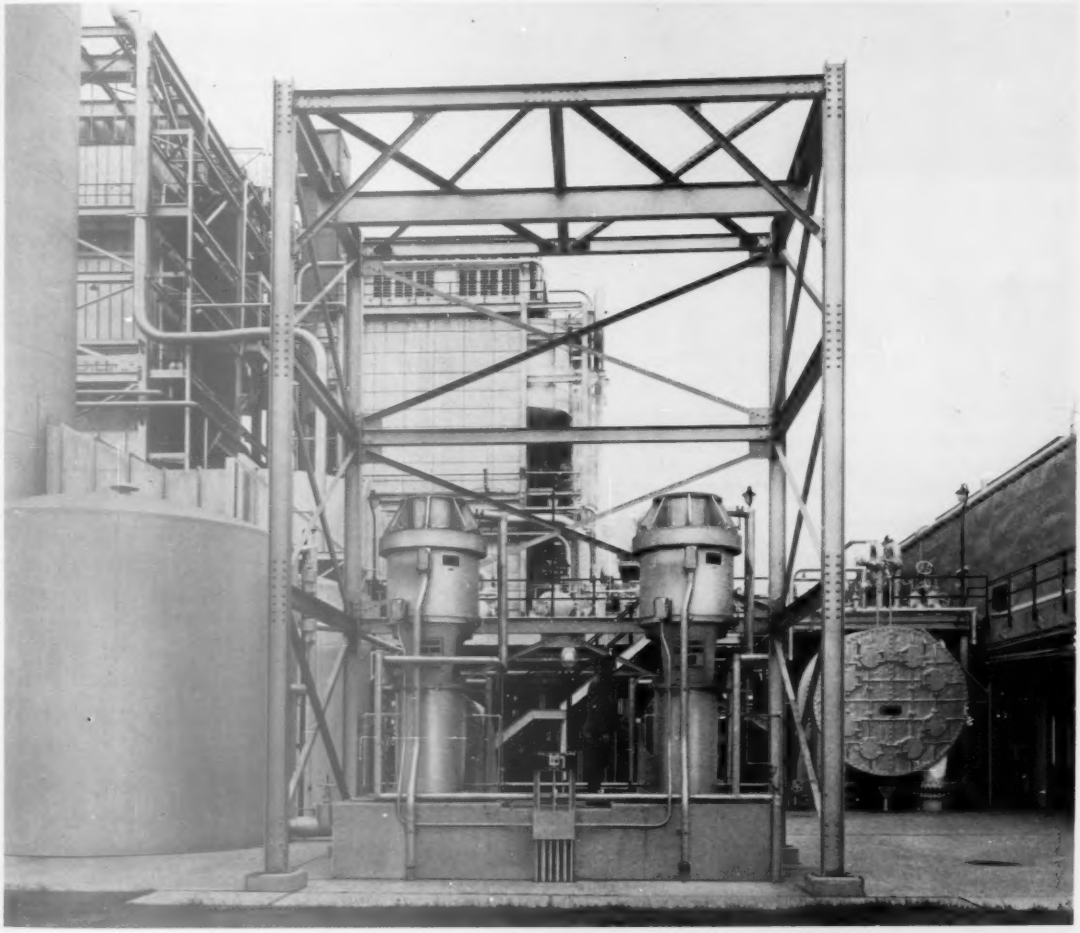
The latest weather-protected motors, with construction based upon previous experience and newer developments, eliminate the disadvantages and provide greater protection, better accessibility and lower installation cost.

These motors are designed to hold intake air velocity down to 600 feet per minute or less. Design permits complete blow-through on both the air inlets and outlets so that in strong winds the air can blow through without entering the motor windings. Rain gutters protect against droplets of water forming on the edges of the air inlets. Motor shaft heights are of normal elevations. Foundations need not be of special or unusual construction. Air intakes are kept high to avoid ground dust and dirt from blowing in. Filters, when used, are easy to dismantle and clean. Space heaters are used to keep the windings warm and dry during shutdown, and the windings themselves are given special varnish impregnation treatment to further protect against moisture damage.

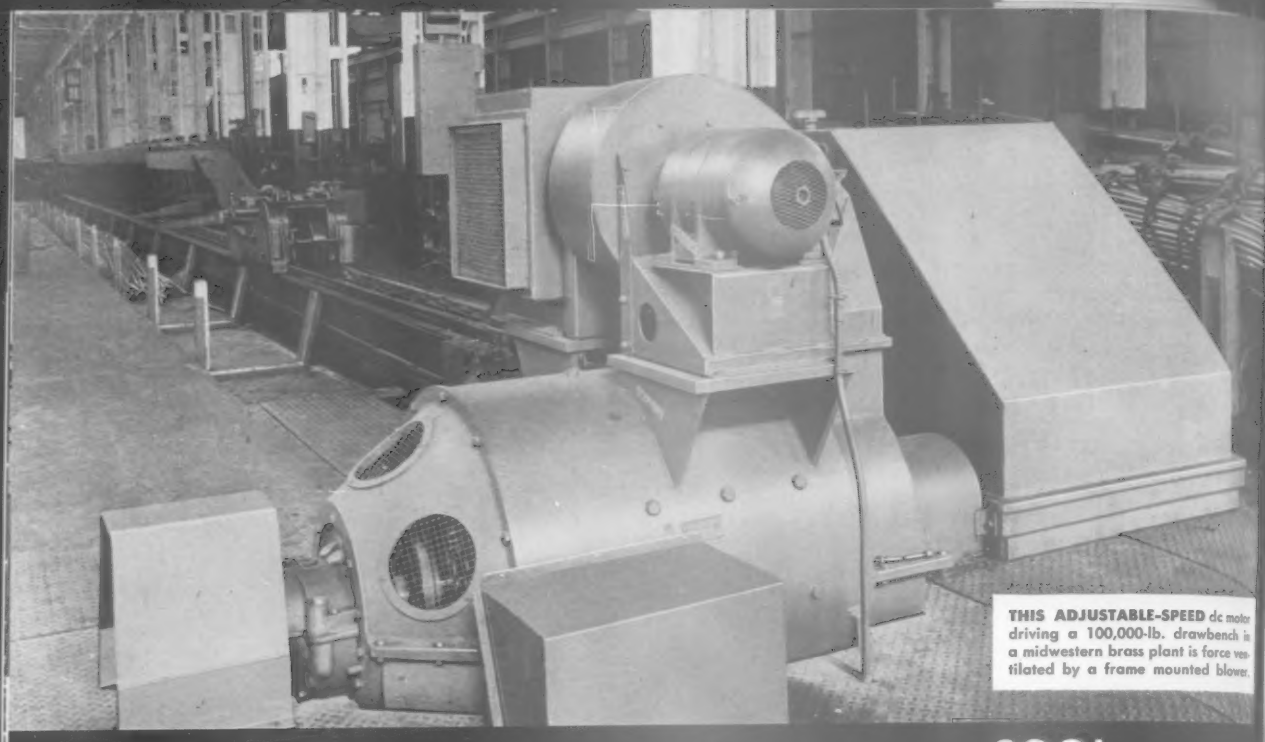
To be satisfied that these motors can do their job, they have been tested in simulated weather conditions as severe as rain at the rate of 40 inches per hour in winds of 75 miles per hour. Results from tests like this show that these improved weather-protected motors are well qualified for outdoor service.

Motors used for outdoor service today are generally of two types: the tube-type, totally-enclosed fan-cooled, and the weather-protected. The tube-cooled motor has the advantage of being adaptable for explosion-proof locations and offers greater protection and reliability. However, the "weather-protected" type is lower in cost and serves many locations adequately.

As time goes on, industry will undoubtedly be confronted with further problems involving motor application, and the continuous course of motor design evolution will be carried on.



**OUTDOOR LOCATION** of motors is a growing trend. These 600-hp, 2300-volt, 875-rpm vertical motors drive circulating pumps in a Midsouth outdoor-type power station.



THIS ADJUSTABLE-SPEED dc motor driving a 100,000-lb. drawbench in a midwestern brass plant is force ventilated by a frame mounted blower.

# FRAME MOUNTED BLOWERS COOL ADJUSTABLE SPEED MOTORS

by **G. BYBERG**
Motor-Generator Section
Allis-Chalmers Mfg. Co.

***When adjustable speed motors operate at low speeds, needed additional cooling can be supplied by frame mounted blowers.***

WHEN ADJUSTABLE-SPEED or adjustable varying-speed drives of about 25 horsepower or more are needed, adequate ventilation to dissipate heat generated by internal losses is frequently a major consideration in both design and operation. Since each class of insulation commonly used has definite heat resisting limitations which cannot be appreciably exceeded without rapid reduction in life expectancy, some means of assuring operation at temperatures below these limits is essential.

The heat generated within the core and windings of any rotating machine is carried to the external surfaces of those parts by conduction. Dissipation of the heat is accomplished in the main by forcing a cooling medium, usually air, over and around the heated parts, augmented to a lesser degree by conduction through and convection from the supporting structure. See Figure 1.

Air circulation within a motor may be adequate for self-cooling. The rotating element itself causes a certain fanning action, the volume of air thus set in motion being dependent on the construction and rotative speed of the particular type of rotor. In exceptional cases, such as some high speed open-type machines of the salient-pole synchronous or induction types, this alone may be sufficient. But, in general, if self-cooling is to be accomplished, the pressure and volume of the cooling medium must be augmented by suitable fans mounted on the rotating element.

Several principles of heat transfer may be employed in a single motor. In a totally-enclosed nonventilated machine the heat is carried mainly by convection through the air circulating within the enclosure, and partly by conduction, to the internal surfaces of the enclosure. The heat is then carried through the enclosure by conduction and dissipated to the external atmosphere by convection. This method is impractical for any but the smaller ratings, since the heat which can be carried by convection through the relatively small internal air volume and dissipated by convection from the exterior "radiating" surfaces is definitely limited. When this practical limit is reached, external fans are added to force air over the external surfaces of smaller size motors, or through a nest of tubes passing through the internal air chamber in larger sizes. These are familiarly designated as totally-enclosed fan-cooled motors.

## Forced air circulation often necessary

Conversely, there are cases of very low speed applications where an open-type machine cannot conveniently be made self-ventilating, even though fans of abnormal size are used on the rotating element. In such cases, or where the machine must be enclosed for other reasons, it is necessary to resort to forced ventilation from an external source. Forced air circulation also may be necessary in the case of some large, lower speed machines using air-to-water heat exchangers and where the rotating element and its fans are incapable of overcoming the pressure drop through the machine and coolers.

When applying forced air circulation to a motor, both size and construction must be considered. For machines of large size, forced air circulation is usually supplied from separately mounted motor driven blowers supplying one or more units. The air may be supplied through ducts to a pit below the machine for up-draft ventilation, or to the machine room for down-draft ventilation, the machine being provided with enclosures to suit the particular method used.

## Frame mounted blower applied

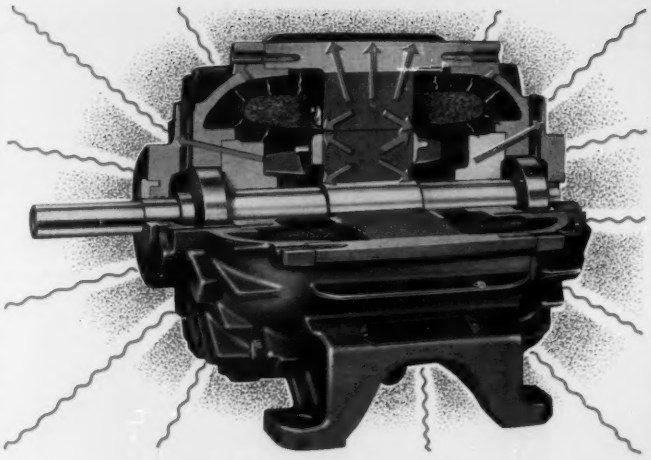
In the case of smaller and intermediate units the above method of forced ventilation may prove impractical or prohibitive in cost. Where this is the case, integral frame mounted blower units are used instead. This provides a compact arrangement which eliminates the need of providing ducts or piping when installing the unit.

When applying a frame mounted blower, the highest speed commensurate with the air volume and pressure requirements is selected. It may be driven by a low voltage (110, 220, 440, or 550 volts) polyphase squirrel-cage motor, or a direct current (115 or 230 volts) motor. The blower motor usually will be of the enclosed type, nonventilated for smaller sizes or fan-cooled for the larger sizes. The motor control should be interlocked with the main machine control so that the main machine cannot be placed in operation until the blower is running.

This frame mounted type of unit is particularly adaptable to intermediate ratings under the following conditions.

## Operation at reduced speeds

Many applications using direct current motors, wound-rotor induction motors, adjustable frequency induction converters, or adjustable frequency synchronous generators, involve operation over wide speed ranges and various conditions of loading, such as variable torque, constant torque, or constant horsepower.



**HEAT GENERATED** within a motor must be dissipated. In this illustration of a totally-enclosed motor, arrows indicate heat being carried by conduction to the surface of motor parts. Heat is partly transferred by convection through air within the motor to the inner surface of the motor enclosure, and by conduction to the exterior surface from where it is dissipated to ambient air by convection as indicated by wavy lines. **(FIGURE 1)**

Assuming that the air moving action of the rotating element and its fans varies with speed in a manner similar to that of a centrifugal fan or blower, then the volume varies directly with the speed, and the pressure varies as the square of the speed. For various ratios of speed ranges under several commonly encountered types of load, we get a table showing approximate relationships as shown in Figure 2.

Offhand, from this table it appears as though sufficient ventilation would be available for operation over the entire speed range, a conclusion which for various reasons would be too optimistic.

In the case of a wound-rotor induction motor at reduced speed, the input kva would be greater than the load proportion, because the magnetizing current remains approximately the same for all speeds. Also the rotor frequency increases, causing increased heating in that

**FIGURE 2**

| SPEED IN PERCENT | VOLUME IN PERCENT | PRESSURE IN PERCENT | LOAD HORSEPOWER IN PERCENT | | |
|---|---|---|---|---|---|
| | | | VARIABLE TORQUE (a) | (b) | CONSTANT TORQUE |
| 100 | 100 | 100 | 100 | 100 | 100 |
| 70.7 | 70 | 50 | 50 | 35.3 | 70.7 |
| 50 | 50 | 25 | 25 | 12.5 | 50 |
| 33.33 | 33.33 | 11.1 | 11.1 | 3.7 | 33.33 |
| 16.66 | 16.66 | 2.78 | 2.78 | .45 | 16.66 |

(a) Torque varying directly with the speed, horsepower as the square of the speed.
(b) Torque varying as the square of the speed, horsepower as the cube of the speed.

| RATINGS | LOAD TORQUE | PERMISSIBLE PERCENT SPEED REDUCTION | PERMISSIBLE PERCENT LOAD HP |
|---|---|---|---|
| General Purpose | Varying | 50 | 40 |
| Large (201 hp and up) | Constant | 30 | 70 |
| Large (201 hp and up) | Varying directly | 50 | 25 |
| Large (201 hp and up) | Varying as square of speed | 75 | 6¼ |

FIGURE 3

member. Hence, a standard open-type wound-rotor motor, rated 40 C at full load and full speed, may be capable of reduced speed operation as a self-ventilated machine, without injurious temperature rise (50 C or 55 C for Class A insulation), approximately as indicated in Figure 3.

The figures relating to large motors are indicative of general practice only and should not be taken as absolutely final for any case.

For constant torque drives requiring more than 30 percent speed reduction, it generally will be necessary to use a larger than normal self-ventilated motor in order not to exceed 50 C rise at minimum speed. A speed reduction of 50 percent may require the next larger horsepower rating; a speed reduction of 65 percent may require the second larger rating. But if forced ventilation is employed, under some circumstances it may be possible to use the normal frame for the required horsepower. Where drives of this class are involved, it becomes worth while to make an overall comparison between a motor having a frame mounted blower and the larger self-ventilating type. Usually, frame mounted blowers increase motor cost less than 10 percent on the larger sizes to approximately 25 percent on small sizes.

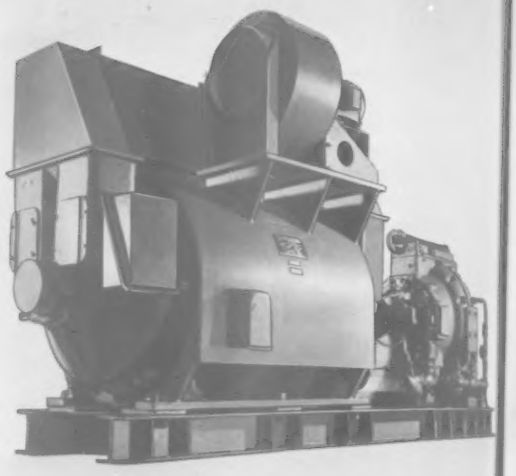
## Wide range frequency converters need cooling

Induction frequency converters are occasionally used to supply power at constant or adjustable frequency to motors on special drives. The converter is essentially a modified wound-rotor induction motor which is driven by an external source of power, either constant or adjustable speed, with the primary circuit (stator winding) connected to a source of fixed frequency. The secondary circuit (rotor winding) delivers energy at a frequency proportional to the relative speed of the primary magnetic field and the secondary member.

Some such applications may involve wide frequency ranges, which means that for corresponding load conditions the converter would be subject to limitations similar to those mentioned for the wound-rotor motor. The secondary frequencies, for the upper speed ranges of the drive, may also be much higher than the applied frequency. In such cases it is imperative that forced ventilation be employed. An example of this kind is shown by Figure 4.

## Dc motors have wide self-ventilated range

Direct current motors operating on variable voltage and having variable torque loads can usually operate self-ventilated over quite a wide speed range. With constant torque loads, normal motors can usually be operated self-ventilating down to one-third of rated full voltage, full



**A FRAME MOUNTED BLOWER** cools this induction frequency converter which supplies adjustable frequency in the range of 10 to 54 cycles to a 1,000-hp squirrel-cage motor. **(FIGURE 4)**

field speeds, but may be limited to two-thirds or one-half of rated speed in case of low armature inertia requirement. Below these limits it ordinarily becomes necessary either to use larger frames or resort to forced ventilation. The latter may in many cases become the more economical.

Direct current motors operating over a wide speed range by means of shunt field control must be designed on the basis of the maximum continuous horsepower required at basic (full field) speed. The exceptions to this are the "tapered horsepower" ratings in the general purpose class, where the horsepower at basic speed is the next lower standard rating below that required at 300 percent speed. All such motors are ordinarily self-ventilating, except at extremely low basic speeds.

However, when motors of this class are required to meet minimum armature inertia characteristics for reversing drives, such as are often encountered in metal rolling mill, metal processing or other drives, the physical proportions frequently become such as to render self-ventilation at all speeds impossible. Figures 5 and 6 show two motors of this class, both having low armature inertia and frame mounted blowers with replaceable glass-fibre air filters.

## Frame mounted blowers have many uses

The frame mounted blower system of ventilation will sometimes find practical application where a machine of moderate size is to be located in a confining and poorly ventilated room. This eliminates the danger of recirculating heated air discharged from the machine. In such a case the air intake or discharge ducts, or both, may be brought out to the nearest source of normal temperature air. If dust and dirt are also unavoidably present, re-

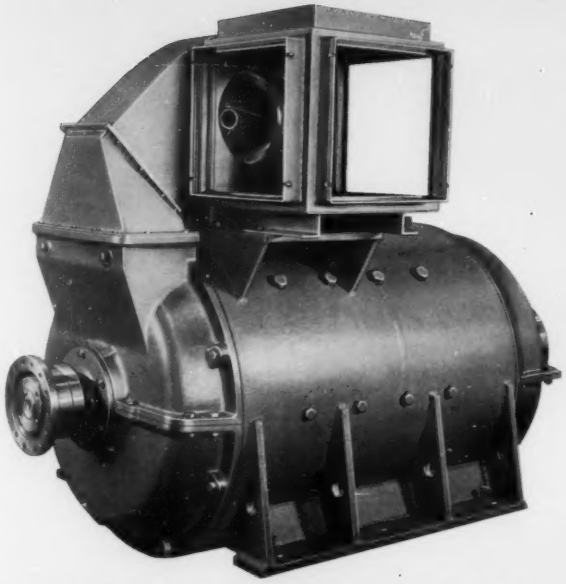
placeable or washable air filters can be provided for the inlet.

An example in which both speed range and confined space render forced ventilation necessary is a direct connected ship-propulsion motor. This may be a synchronous motor operating on a variable frequency or a direct current motor, usually located in a confined space near the propulsion shaft alley.

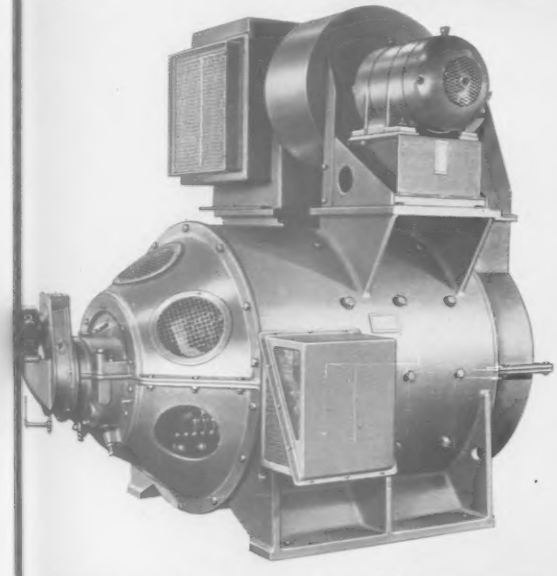
A combination of speed range and ventilating conditions is illustrated by the oil well drilling rig draw works motor in Figure 7. The blower assures ample ventilation when the motor is developing full torque at reduced speed. In order to avoid explosive air mixtures, it may also be desirable to bring air to the blower by means of a duct having its intake located some distance from the rig.

In order to assure adequate forced ventilation, a frame mounted blower must be coordinated to the machine's needs and its duct work constructed to direct the forced air for most effective cooling. If filters are used, their effect on air volume and velocity must be considered and the applied blower selected accordingly. Since frame mounted blowers are located for efficient operation and economical construction, their position may vary from one installation to another.

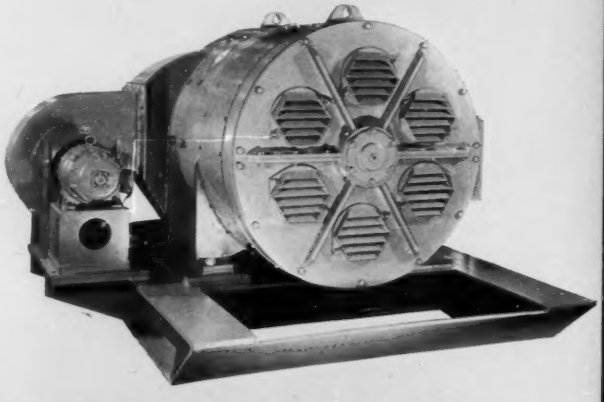
When compared with oversize motors, motors with frame mounted blowers for forced ventilation have several advantages. Original cost in many cases may be substantially less. Full speed operation is more efficient and more economical because the motor runs at its full capacity. Even at reduced speeds, the combined input to the motor and its blower drive may be less than to an oversize motor. However, because of the many factors involved, the choice between an oversize motor and a frame mounted blower for forced ventilation should be considered on the basis of the individual installation.



**COOLING** this 100-kw, 125 to 475-rpm drag-generator for a skin-pass mill requires a frame mounted blower. **(FIGURE 5)**

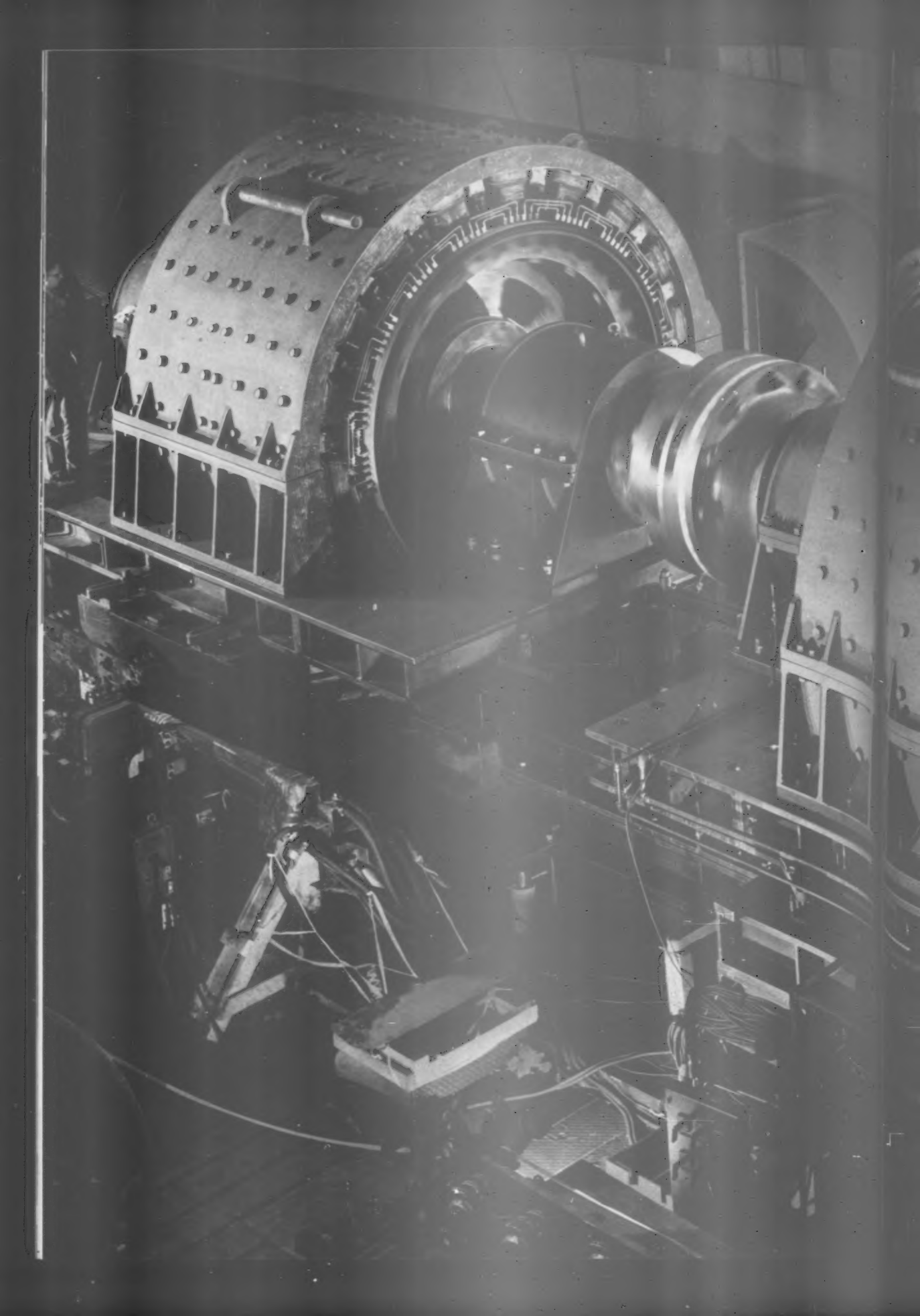


**HIGH HEAT LOSSES** at low speeds necessitate a frame mounted blower for forced cooling of this 400 to 1200-rpm, 300-hp direct current drawbench drive motor. **(FIGURE 6)**



**THIS OIL WELL DRILLING RIG** draw works motor has a frame mounted blower to assure ample ventilation when developing full torque at reduced speed. **(FIGURE 7)**

**TEAM OF WORKHORSES** for the steel industry, these 5000-hp direct current motors are coupled together for test purposes. When installed in a southern Illinois steel plant, they will power top and bottom rolls of a twin drive blooming mill.



# SELECTING GENERATORS for Hydro-Electric Plants

by **H. H. ROTH**
Motor-Generator Section
Allis-Chalmers Mfg. Co.

**SUSPENDED-TYPE GENERATORS** were selected for this hydro-station because of the high speed (400 rpm) and 16,667-kva rating.

*Here is an analysis of major hydro-generator types, their enclosures, and conditions under which each is preferred.*

GENERATORS BUILT FOR STEAM-ELECTRIC plants have been standardized by the power industry to the extent that relatively few modifications are permissible. For hydro-electric applications, however, a completely new generator design is required for each station and features best suited to the individual application can be selected.

As a result of this latitude in design, there are available several general types of hydro-generators, each having a considerable number of possible modifications. The general field of application for each general type is shown in Figure 1. The dividing lines between the types shown in this figure are approximate and will vary with the physical and electrical characteristics required for the particular rating involved.

When selecting the most suitable hydro-generator, and determining the modifications that best adapt it to a particular plant, consideration must be given to the advantages and limitations of each general type.

## Horizontal units economical in small sizes

Small high speed generators are available in horizontal shaft units only. This is largely a matter of economics rather than inability to build such ratings for vertical shaft settings. For an installation involving a relatively small generator rating, the installed cost of a horizontal shaft turbine and generator will usually be somewhat less than for a vertical shaft unit. As a result, there is little demand for these ratings as vertical shaft units; consequently the smaller ratings are shown in Figure 1 as available in horizontal shaft construction only.

Larger units are also available in horizontal shaft construction. Such generators have been used extensively in the past, principally with impulse type turbines where hydraulic requirements made horizontal shaft settings desirable, and with moderate size Francis turbines. Recent development of the multi-jet vertical impulse turbine has reduced the field for larger sizes of horizontal shaft generators. A typical installation of a modern horizontal shaft unit is shown in Figure 2.

## Vertical generators have hydraulic advantages

Hydro-electric power installations for moderate and large capacity installations are now usually of the vertical shaft type. There are hydraulic advantages to such settings, since both reaction and propeller type turbines are usually set with the centerline of the turbine runner below normal tailwater elevation. This is done to reduce cavitation or pitting of the turbine runner. Vertical shaft construction permits setting the generator a sufficient height above the turbine to prevent damage during stream flood conditions when the tailwater may be excessively high.

When impulse turbines are used, runner cavitation is not a factor. However, the impulse runner is set as close to the tailwater as possible, to take full advantage of the available head.

There are also mechanical advantages to vertical settings. For example, it is obviously easier to properly support a large generator stator by means of sole plates around its entire periphery than by means of two stator feet as are used for horizontal shaft generators.*

## Earliest vertical units were suspended type

For earlier hydraulic power developments vertical shaft generators were all of the suspended type, with the thrust bearing and one guide bearing located above the generator

* See *Hydro-Generators — Rugged Individualists,* Roth, H. H., Allis-Chalmers *Electrical Review,* Fourth Quarter, 1951.

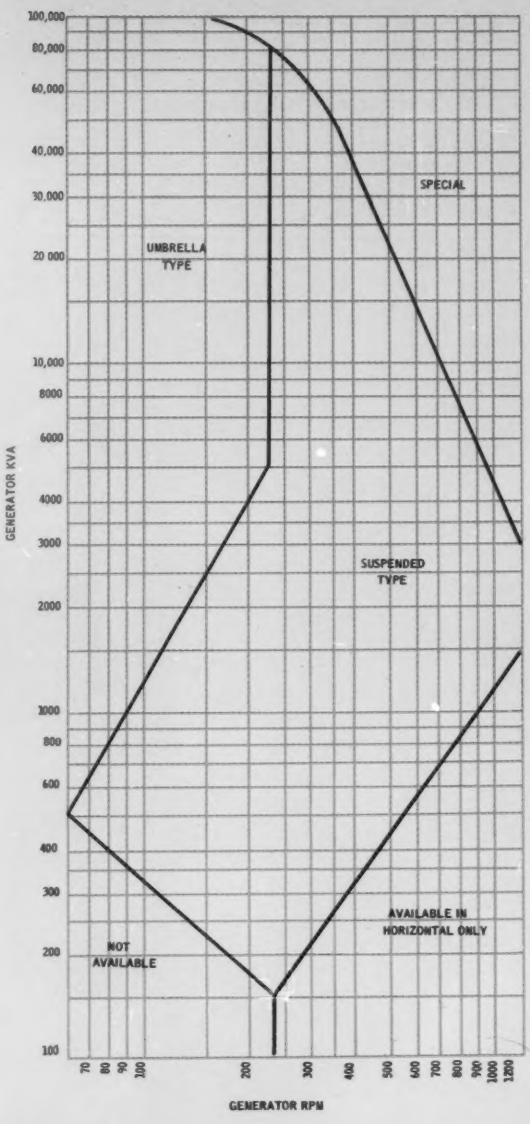
rotor, and with an additional guide bearing beneath the rotor. Such units are generally used for speeds of 225 rpm and above, and for lower speeds where the kw rating of the units is small, since the umbrella type is not suited for such applications. This type of construction can be used for all vertical shaft units, but for large low speed ratings it has been displaced in recent years by the umbrella-type machine.

With the suspended-type generator the total thrust load, including the weight of the turbine shaft and runner, the hydraulic thrust load of the turbine, and the weight of the generator rotating parts, is transmitted to the foundation through the generator stator. This results in a relatively large upper bearing housing which spans and is supported by the stator yoke. The lower bearing housing contains only a guide bearing, but must also have sufficient strength to support the weight of the generator and turbine rotating parts on the hydraulic jacks which are mounted on the arms of the housing, and which are used in the assembly, disassembly, and servicing of the unit.

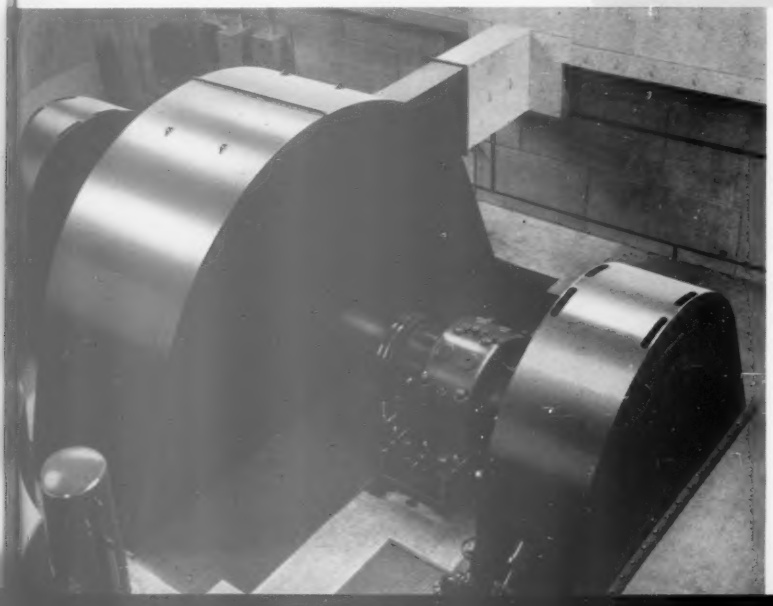
A cross section of a suspended-type unit is shown in Figure 3. To dismantle such a generator the weight is taken off the thrust bearing by means of jacks. The thrust collar can then be removed from the generator shaft, after which the upper bearing housing is removed from the machine. The height of the powerhouse crane is determined, so far as the generator is concerned, by the lift necessary to remove the assembled shaft and rotor from the machine. If several units are installed in the plant, the crane height may be determined by the clearance necessary to move the assembled shaft and rotor over the other machines in the plant.

## Umbrella type limited to low speed

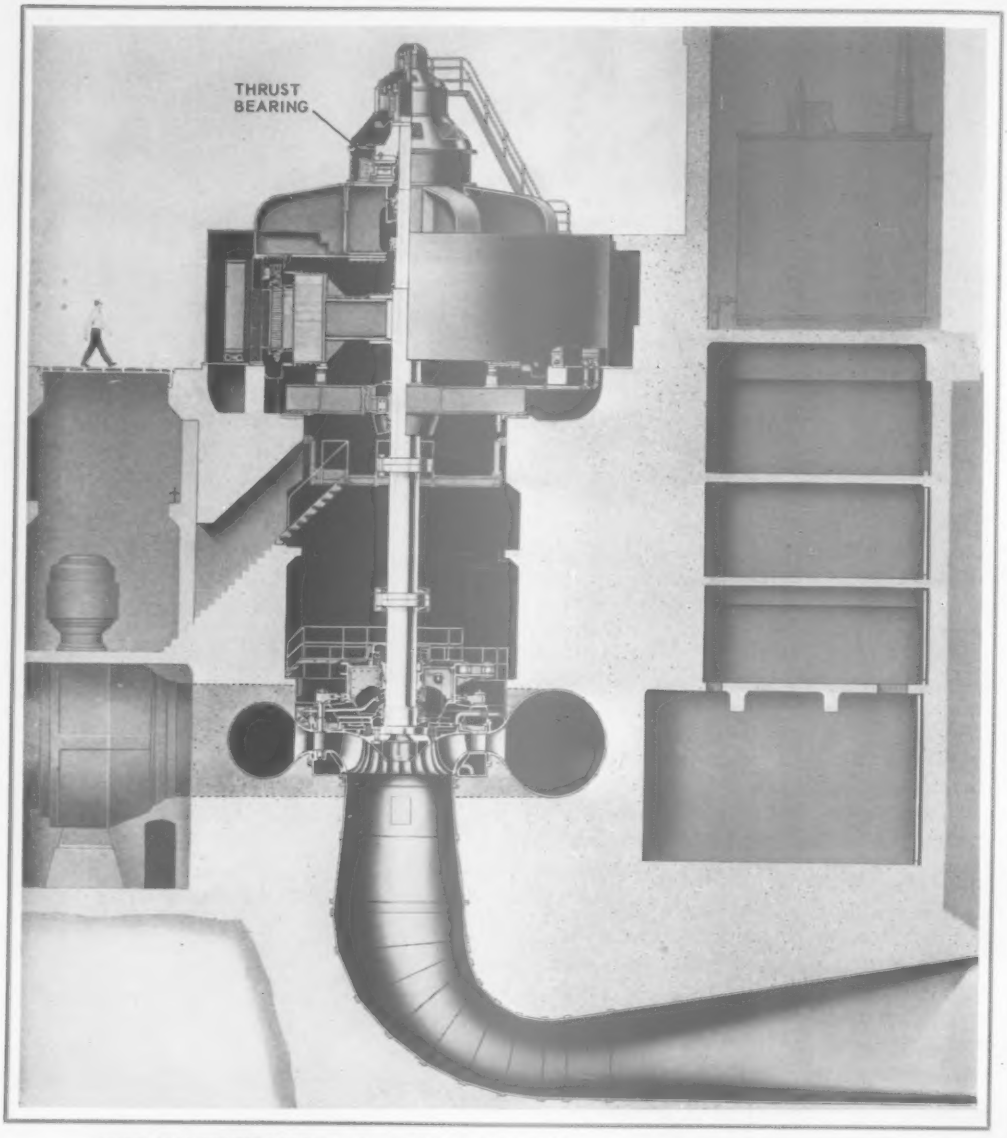
The field of the umbrella-type generator is limited in the larger kva ratings to speeds under 225 rpm, and in the smaller ratings to even lower speeds. Figure 4 shows a cross section through a typical umbrella-type generator. The thrust bearing and a guide bearing are located beneath the generator rotor, and there is no upper guide bearing.




**THE TYPE OF GENERATOR** best suited for a particular application is dependent upon kva rating and rpm. Preferred applications for each is indicated by the blocked-in areas. **(FIGURE 1)**



**THIS HORIZONTAL SHAFT** generator is driven by a double overhung turbine rated 30,000 hp, 257 rpm with a 1150-ft hydraulic head. **(FIGURE 2)**




**HYDRAULIC THRUST LOAD** plus the combined weight of turbine and generator rotors is transmitted to the foundation through the generator stator in suspended types such as this 82,500-kva machine. **(FIGURE 3)**

The upper limits of speed for the umbrella-type generator as shown in Figure 1 are determined by considerations of the physical stability of the generator rotating parts. Generally speaking, this is a function of both rotor diameter and rotor height. This determines the location of the rotor center of gravity with respect to the point of support — the thrust bearing. The rotor diameter is usually determined for a given kva rating by the unit rpm, although considerations of overspeed and $Wk^2$ may affect the diameter.

For smaller kva ratings, the generator diameter becomes smaller; consequently it becomes difficult to find sufficient room beneath the generator stator to install the large bearing housing of an umbrella-type unit and provide sufficient room for proper servicing of the thrust bearing. Hence for the smaller ratings, umbrella-type construction is limited to lower speeds, which require increased diameter generators.

To dismantle an umbrella-type machine the exciters and exciter support bridge are removed. The generator rotor is then unbolted from and lifted off the thrust block, which forms the upper portion of the shaft. The shaft can then be removed from the bearing housing or can be removed with the bearing housing as shown in Figure 5.

The shorter shaft of the umbrella-type machine, combined with the fact that it can be handled separately from the rotor, may make it possible to lower the elevation of the powerhouse crane, thus affecting a saving in building costs. The generator height above the floor line is also less with umbrella-type construction, requiring less crane lift when moving generator parts over adjacent units. In some cases a smaller crane may be used, since the rotor is handled independently from the generator shaft. An actual comparison of relative generator heights and crane clearances for umbrella-type and a suspended-type generator of exactly the same rating is shown in Figure 6.

## Modified umbrella type permits higher overspeed

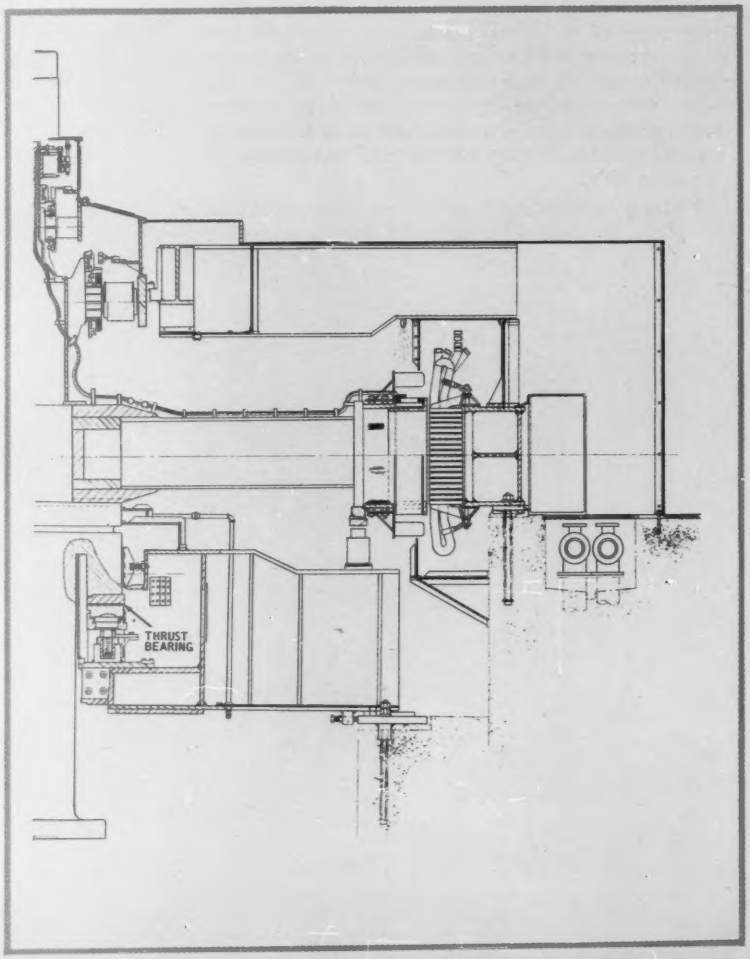
In certain cases it may be desirable to use an upper guide bearing with an umbrella-type generator. A machine with such a bearing arrangement is known as a modified umbrella generator. A cross section of this type unit is shown in Figure 7. When it is desirable to shorten the generator shaft to reduce building height, a stub shaft extension can be used above the generator rotor. This removable stub shaft permits handling the main shaft separately.

The modified umbrella-type generator finds its application in borderline cases between the suspended and the umbrella machines, where the use of a true umbrella-type generator might be questionable. The upper guide bearing may also be of advantage where the generator is driven by a turbine with high overspeed, such as is sometimes obtained with a Kaplan turbine. Extremely high overspeed might require the use of a smaller diameter rotor than would otherwise be used, resulting in a greater pole length. The physical stability of such a machine would be decreased, and an upper guide bearing might prove desirable.

Each case, however, should be considered on its own merits. A high percent overspeed does not necessarily mean that an upper guide bearing will be necessary. For example, a 25,000-kva, 100-rpm generator with 160 percent overspeed will operate at 260 rpm at full runaway. True umbrella construction will be entirely adequate for this runaway speed. On the other hand, an upper guide bearing might be advisable for a 25,000-kva, 180-rpm machine also having 160 percent overspeed, since the full runaway speed would be 468 rpm.

## Housings facilitate cooling-fire protection

Earlier installations of hydro-generators were all of the open, self-cooling type. Cooling air was usually taken into the generator from the turbine pit and discharged




**UMBRELLA-TYPE GENERATORS** have both thrust and guide bearings beneath the generator rotor. Top speed is limited by physical stability of the rotating parts. Generator rotor spreads out above the bearings like a giant umbrella. **(FIGURE 4)**

**SHAFT AND BEARING HOUSING** of this 18,000-kva, 13,800-volt, 112.5-rpm synchronous generator are being installed together. Shorter shaft length of umbrella-type units plus separate handling of rotor and shaft permits lower powerhouse cranes, reduced building height. **(FIG. 5)**

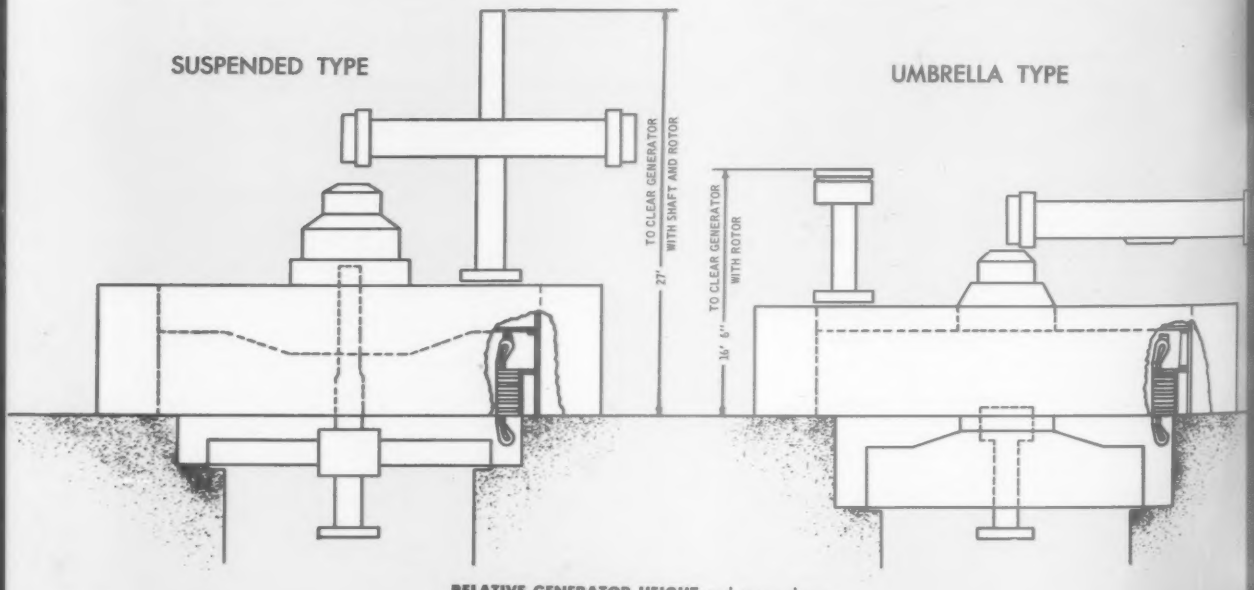
into the generator room. Machines up to 5000 kva and even larger are still installed with open-type cooling.

However, most of the larger machines built today have an enclosed recirculating-type cooling system with generator air coolers. An air housing is provided to enclose the generator above the generator room floor line, and the turbine pit is sealed beneath the generator, usually by means of steel plates mounted on the bearing housing. Since the same air is used over and over to cool the generator, the generator core and coils remain much cleaner than if outside air were continually drawn into the machine. The enclosed cooling system keeps the temperature of the generator room at a more comfortable level during summer months, limiting the maximum temperature of the air to 40 C.

Enclosed machines also permit the use of carbon dioxide fire protection systems because the housing confines the gas to the generator enclosure. On an open-type machine, $CO_2$ systems are not effective because the rotor fans blow the gas away as fast as it is released by the fire protection system.

The air housings and coolers of enclosed-type machines may be arranged so that in winter months a portion of the hot air from the machine may be discharged into the powerhouse for heating purposes. Openings must also be provided in the housing for air return into the generator. When $CO_2$ fire protection systems are used with such machines, the air inlet and outlet openings can be arranged for automatic closing upon operation of the $CO_2$ system.

In some cases it may be desirable to use open-type generators for even relatively large ratings. For example, there are a considerable number of single unit unattended stations now being built. If such a station is located in




**RELATIVE GENERATOR HEIGHT** and crane clearance for 30,000-kva, 13,800-volt, 164-rpm suspended and umbrella types are indicated. **(FIG. 6)**

an area where extremely low temperatures prevail in winter months, it may be desirable to omit the air coolers, eliminating the possibility of freeze-up when the machine is off the line. In such cases fire protection can be obtained by means of water spray nozzles located above and below the stator windings.

## Outdoor-type housings

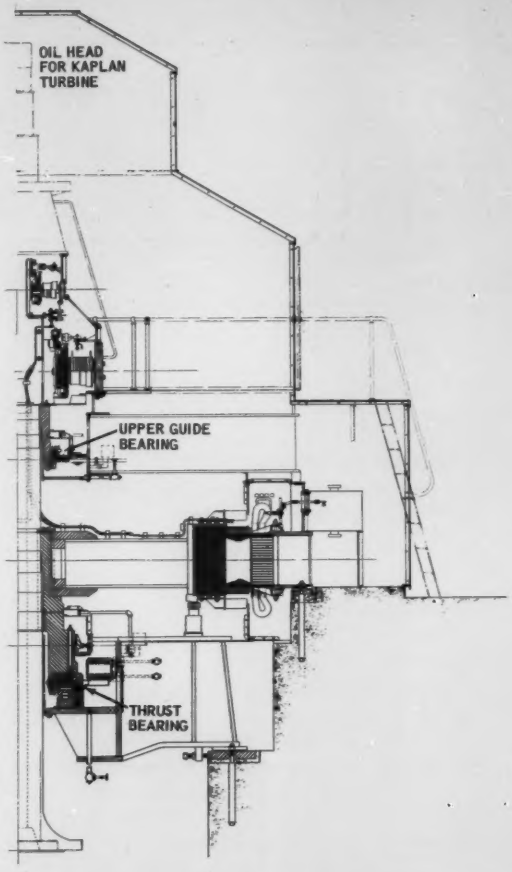
Where climatic conditions are suitable, it may be economical to use outdoor-type generators. This permits eliminating the powerhouse structure above the generator floor level, as each generator is provided with a weather-proof housing. The housing may be arranged with coolers for a recirculating type cooling system, or for open-type cooling. A gantry crane is used for assembly and disassembly of the generators and turbines.

Outdoor-type units are particularly suited to areas of low rainfall, such as are found in the western half of the United States. At least a portion of the outdoor housing must be removed from the machine when effecting repairs on the generator or turbine. In areas of high rainfall this makes protection of the generator difficult during periods of service work, and indoor-type machines are preferable.

An outdoor housing as applied to a modified umbrella-type generator is shown in Figure 8.

## Indoor housings

Indoor-type air housings are built in several types to suit the requirements of the installation. Some of these housings are shown in Figures 9 through 12. Figure 9 shows a conventional housing for a suspended-type generator where the top of the housing is supported by the upper bearing housing. The air cooler sections are spaced sym-




**UMBRELLA-TYPE GENERATORS** can be modified for increased physical stability by adding an upper guide bearing. **(FIGURE 7)**

**AN OUTDOOR HOUSING** is used on this 8400-kva, 225-rpm modified umbrella-type generator. **(FIG. 8)**

**THIS CONVENTIONAL INDOOR HOUSING** for a suspended-type generator has air cooler sections spaced symmetrically around the outside of the stator yoke. **(FIGURE 9)**

**IF SPACE IS LIMITED,** a large single-section air cooler located on one side of the machine will reduce the overall housing diameter from that required for symmetrically placed coolers. **(FIGURE 10)**

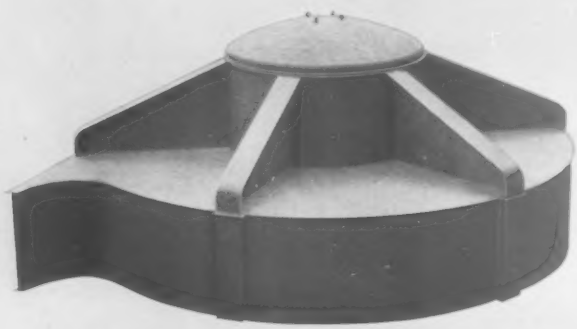
metrically around the outside of the stator yoke, and there is sufficient clearance within the housing to permit walking past the coolers.

In some installations, space limitations may make the type of housing shown in Figure 10 desirable. The air cooler is a large single-section unit, located on one side of the machine. The air housing diameter is thus reduced, except for that portion containing the cooler. For larger units a two-section air cooler with the sections placed diametrically opposite each other may be preferable.

In some areas generating equipment must be protected from severe dust conditions, such as the dust storms that have been encountered in the Southwest. The generator is well protected by its air housing, but for such installations it is also necessary to enclose the exciters, and to ventilate them from the generator cooling system. Figure 11 shows a combined generator and exciter air housing, which in this case is arranged for a single large air cooler section.

Even when air coolers are not used, it may be desirable to use some type of generator air housing. Figure 12 shows the upper portion of a housing for a machine with an open-type cooling system. Outdoor air is drawn into the generator through the two large rectangular openings on one side. These are located in building wall openings and are provided with replaceable filter elements to remove dust from the cooling air. The air is then drawn downward into the generator rotor, passes through the stator, and is discharged either into the generator room for heating purposes or through a duct to the opposite side of the powerhouse. The generator for which this particular housing was built uses a concrete barrel-type setting. The generator stator is set in an octagonal pit beneath the generator room floor level. The walls of this pit form the vertical sections of the air housing, and it is only necessary to provide the upper cover and air intake ducts as shown.

The selection of the type of hydro-generator for a particular installation depends upon the characteristics of the hydraulic turbine as well as the kva rating and speed of the unit. Umbrella-type generators may result in savings in powerhouse costs, but their use is limited to the lower speeds. For relatively high speed vertical units, only the suspended-type generator is suitable. For the smaller high speed units, horizontal shaft units are usually most economical.



**BOTH GENERATOR** and exciter are enclosed within this housing and ventilated from the generator cooling system, which is arranged for a single large cooler. **(FIGURE 11)**

**THIS HOUSING FOR AN OPEN-TYPE** cooling system draws outdoor air into the generator through the large rectangular ducts, then discharges it into the powerhouse. **(FIGURE 12)**

**FIVE WIND TUNNEL DRIVES** having 16,000-hp, 3600-rpm synchronous motors with 2500-hp wound rotor starting motors plus an incoming power supply consisting of three 33,333-kva power transformers are controlled by this 15-panel duplex control board for a new Air Force test facility. Terminal blocks placed vertically on wiring troughs are readily accessible. Instrument, meter, relay, and control device terminals are convenient for inspection and testing. The panel, with its more than 300 relays and 290 annunciator points, is a good example of adequate instrumentation and control, and is consistent with the best switchboard practice.

# NEW GROUNDING DEVICE

## Simplifies Testing of Installed Switchgear

by **H. H. ACKMANN**
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**and J. F. CHIPMAN**
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*Personnel safety holds first place in the step by step development of test equipment for metal-clad switchgear.*

THE GREATEST FACTOR in the safety of present-day metal-clad switchgear is the thorough isolation of all live parts. This same inaccessibility created numerous test problems. Steel panels are bolted to a welded structure enclosing the bus, the circuit breaker, the current transformers, and the incoming and outgoing cables. When the circuit breaker is in the connected position it is practically impossible to gain access to any live parts; and when the circuit breaker is removed from the fixed structure, automatic shutters cover the openings through which the circuit breaker makes its connections to the bus and the current transformers, thereby preventing access to any of the high potential parts.

When metal-clad switchgear was introduced to the power industry, this inaccessibility created test problems not previously encountered. On older installations, conductors were readily accessible in their concrete and steel frame compartments. For grounding and testing procedures, accepted practice was to clamp or bolt connections to the exposed conductors.

This procedure, while common, was quite hazardous to the personnel conductiong these required tests. On the other hand, metal-clad switchgear was safe, but it was generally conceded that it could not be universally accepted without some provision for a test flexibility approaching that of the old open-type switchgear.

### Early devices had limitations

The first attempt to overcome the lack of flexibility of metal-clad switchgear for power systems was made on a 2300-volt delta system with radial feeders. The grounding device shown in Figure 1 when racked into the switchgear unit in place of a circuit breaker provided some flexibility but introduced other safety problems. This device provided a choice of line or bus grounding through interchangeable bushings but made no provision for ungrounded testing.

Before this grounding device could be placed in the connected position between the ground bus and the feeder cables, it was necessary to determine whether or not the feeders were energized. As a result, an ungrounded test device was subsequently developed. This dummy breaker, shown in Figure 2, did nothing more than make the terminals for the line and bus accessible. In this way, the terminals could be tested for potential before a portable ground cable would be connected to them.

A later device, shown in Figures 3 and 4, provided access for potential check before grounding and incorpo-

rated a grounding switch. The grounding operation was accomplished by means of a manual handle on the front of the device. While grounding the outgoing cable was considered the most important function of this device, for various reasons it was also advantageous to use this device for grounding the main bus of the switchgear. This was accomplished by arranging the bushings so that they could be placed at either end of the device.

These various types of early test devices did not maintain the high standard of safety to personnel associated with metal-clad switchgear. These devices could be dangerous if accidentally applied to a live circuit. To overcome this disadvantage, grounding devices such as shown in Figure 5 were built to withstand full short circuit current stresses without damage to the device or danger to personnel. Although the grounding devices solved the problem of safety, they lacked flexibility because they were designed to ground either the bus or outgoing cable. A grounding device capable of both these functions was very expensive. Then, too, this device did not answer all the requirements for phasing out and meggering outgoing circuits, since there were no terminals accessible for these test connections.

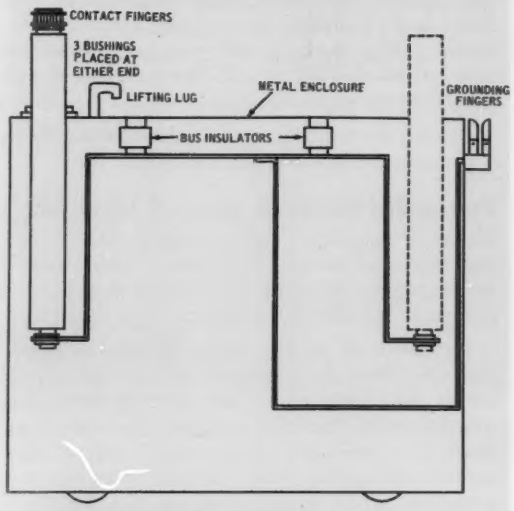
Thus the manufacturers of metal-clad switchgear came to recognize the need for a device that would perform the functions of grounding, phasing out and meggering both the bus side and the outgoing cable side of the respective units while maintaining the accepted standard of safety to the personnel.

It was apparent that to facilitate grounding, testing, and the possibility of providing a ready means of emergency power take-off or feed to the modern metal-clad switchgear unit, a new device, safer and more versatile than any heretofore available, would be required. It was with this in mind that the present grounding and test device was developed.

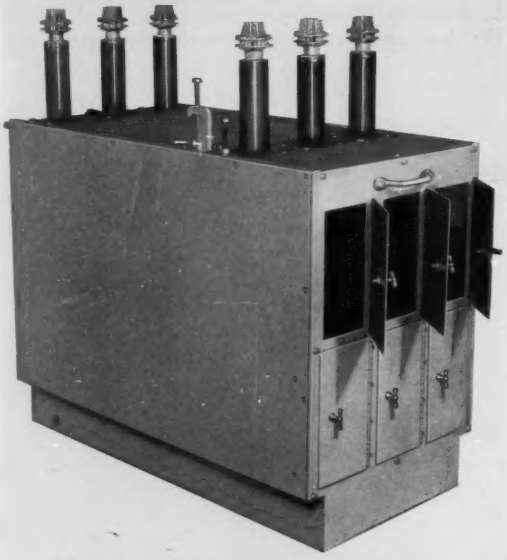
## Units now safe and versatile

This grounding and test device was designed primarily for use in place of a standard power circuit breaker in the vertical-lift type of metal-clad switchgear. As such, it had to provide the same dielectric strength as the circuit breakers normally applied therein, and had to be in accordance with the applicable industry standards. To safeguard personnel in case of human error, the device had to provide a means of checking to assure absence of potential on the line or bus it was to ground. Furthermore, should the device be accidentally closed on a live circuit, it had to have the ability to safely withstand without distress the full short circuit currents of the system to which it was applied. In addition to these safety features, which are in keeping with the principle of metal-clad switchgear, the test device had to be simple, easy to operate, and convenient to use.

The new unit is similar in appearance to a standard vertical-lift power circuit breaker and contains the following principal components: a full set of bushings equipped with standard primary contact finger assemblies; a selector




**EARLY GROUNDING DEVICES** established a ground on line or bus by being elevated into contact position. Since no provision was made for preliminary testing with these units, they were considered inadequate. **(FIGURE 1)**



**UNGROUNDED TESTING DEVICE** merely made the terminals of the switchgear accessible. While reasonably convenient to use, this device did not incorporate all the safety features normally required. **(FIGURE 2)**

switch assembly for providing line or bus connections; a set of grounding contact disconnect blades; a solenoid operated mechanism for actuating the grounding contact blades; and a test panel for providing selective access to the live parts of the metal-clad switchgear. Various interlocks are also provided, as well as a remote control station for closing the grounding contacts from a safe distance.

Figure 6 is a general view of the device, while Figure 7 is a phantom view identifying the various parts.

## Ungrounded test made safe and convenient

During the installation and checking of a line of metal-clad switchgear, the test device finds ready use in the various ungrounded tests which must be made before the equipment can be safely energized.

The device set up for ungrounded tests is shown in Figure 8c. With the device removed from the switchgear cubicle, the selector switch contacts *E* are set in contact with the rear or "line" side terminals. The selector switch handle *D*, a removable hand operated crank, is used to position the selector switch contacts. With the switch set on line contact, the key in the interlock *B* on the rear of the device can be turned to lock the selector switch setting and to open an electrical contact in the solenoid operator circuit. The key is then removed from the rear interlock, inserted in the front interlock, and turned to unlock the cover over the bus test terminals *H*. Thus, all line and bus connections are available at the front of the device, and the grounding contacts cannot be closed. If by chance the grounding contacts are already closed when the above settings are made, the elevating gear interlock

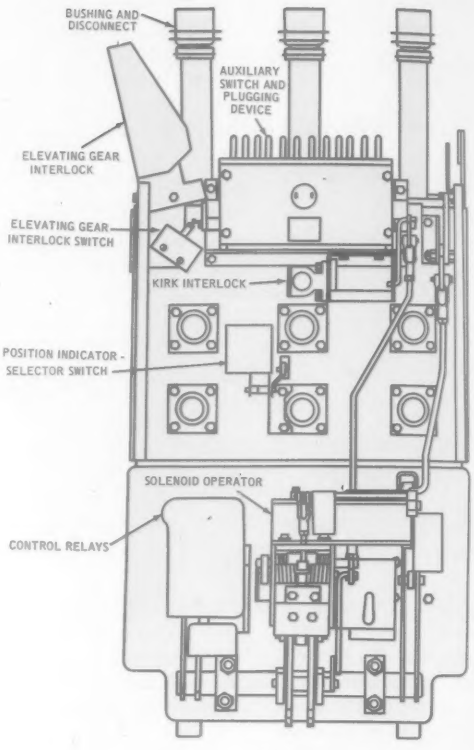
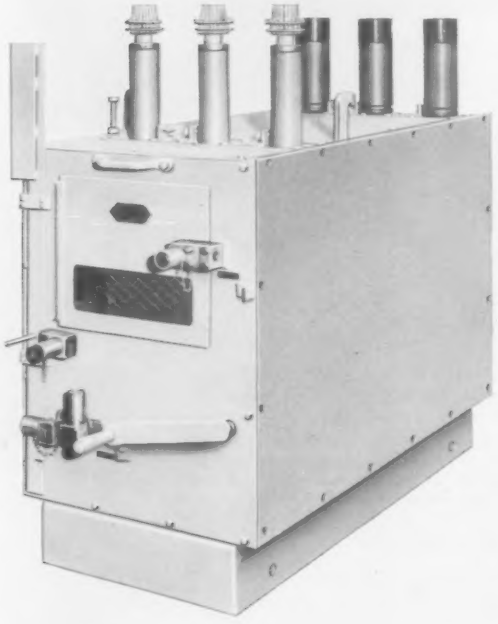
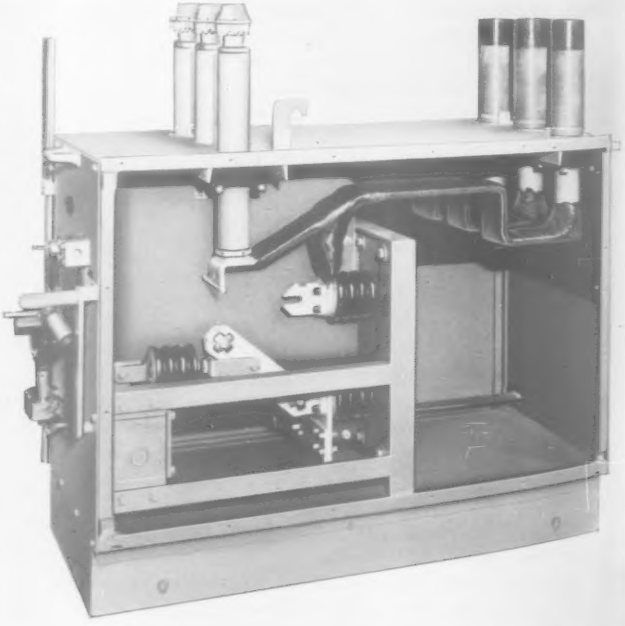



**FIGURE 7a**



**GROUNDING OF LINE OR BUS** was predetermined by the placement of the main bushings on this device. Interlock scheme provided a degree of safety. **(FIGURE 3)**



**CIRCUIT CONFIGURATION** of the device in Figure 3 is shown. Accidental grounding of live terminals could be hazardous, since grounding was manual. **(FIGURE 4)**

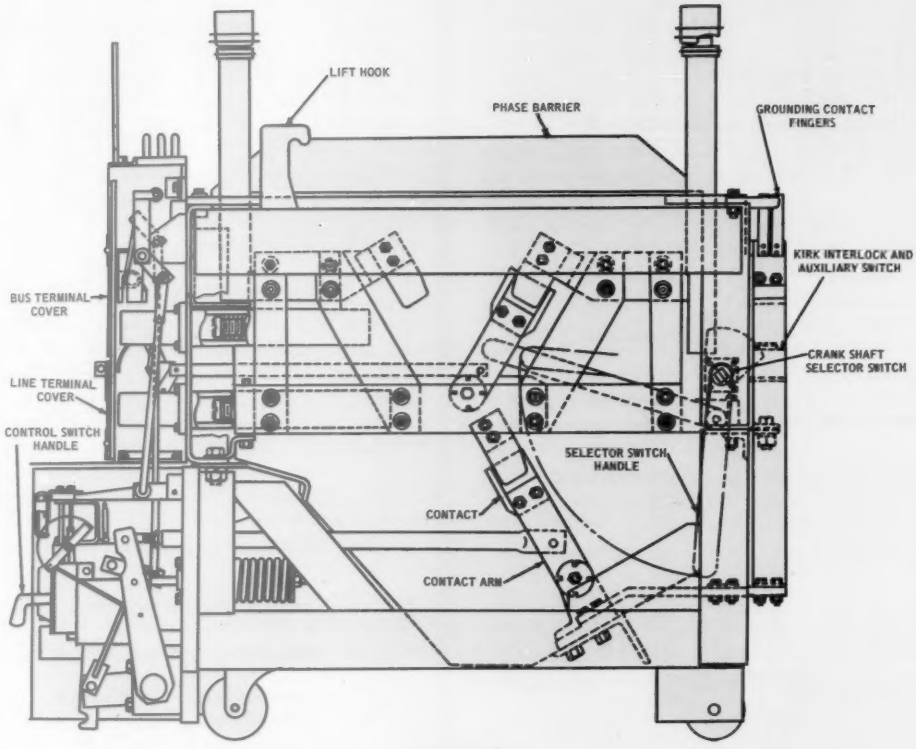
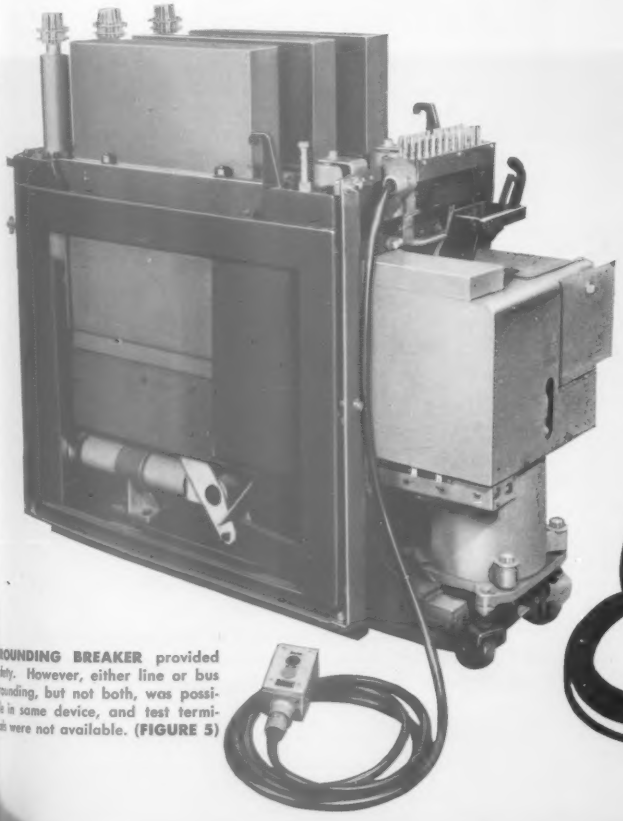
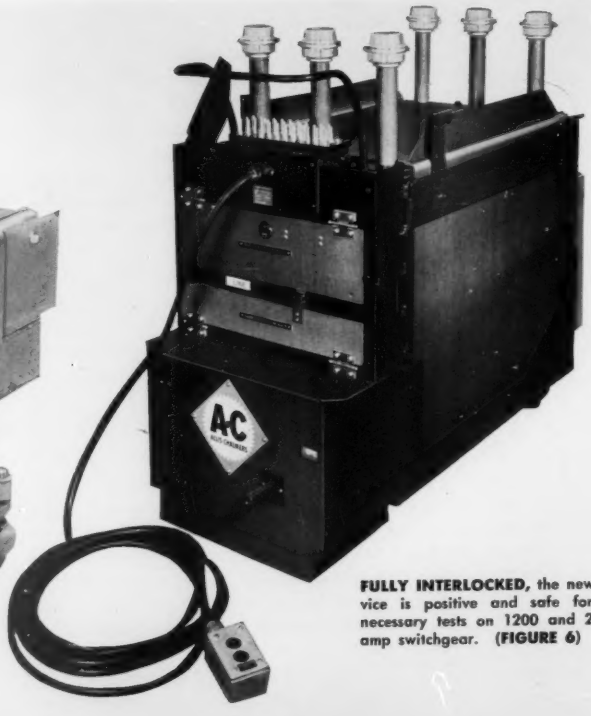



**FIGURE 7b**



**ROUNDING BREAKER** provided
ety. However, either line or bus
rounding, but not both, was possi-
e in same device, and test termi-
s were not available. **(FIGURE 5)**




**FULLY INTERLOCKED,** the new device is positive and safe for all necessary tests on 1200 and 2000-amp switchgear. **(FIGURE 6)**

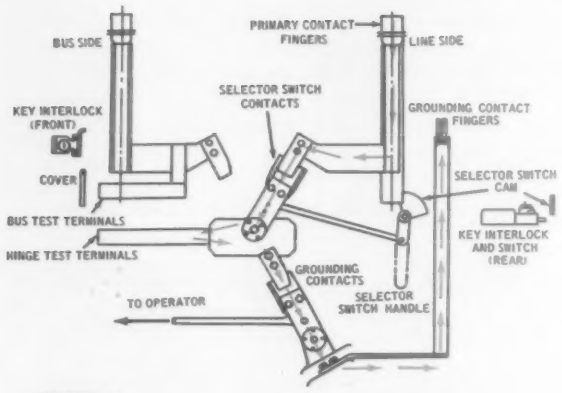



FIGURE 8a

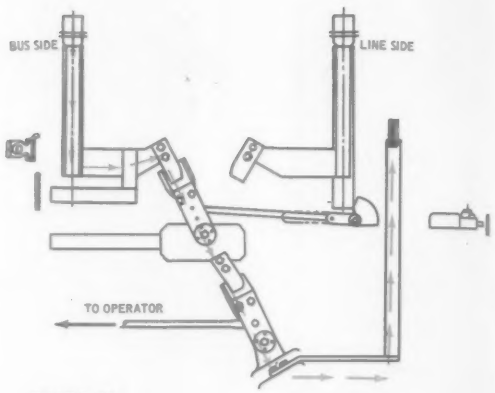



FIGURE 8b

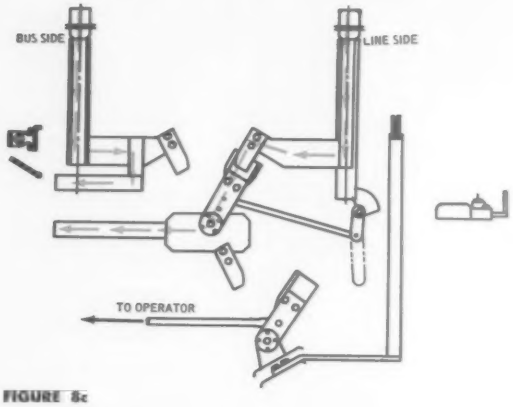



FIGURE 8c

**GROUNDING LINE SIDE (FIGURE 8a)**

**GROUNDING BUS SIDE (FIGURE 8b)**

**PHASING OUT, POTENTIAL OR CURRENT TEST (FIGURE 8c)**

*L* will prohibit insertion of the device into the switchgear cubicle. The standard trip interlock on the device, as on all vertical-lift breakers, acts as an additional safeguard and would open the grounding contacts before the device reached a predetermined position in the elevating mechanism travel. When the settings have been made as outlined above, the device is inserted into the switchgear cubicle and is elevated into position, after which it is ready for use. When the unit is used for ungrounded functions, it does not require a power source for operation, since all settings and operations are manual. This is particularly useful at new installations where the normal control power system is still under construction or is otherwise unavailable.

In addition to the usual testing functions possible with the unit when set as outlined, another important use is as a power carrying link in an emergency or temporary power supply. Since the metal-clad switchgear is protected against easy access to the current carrying parts, the device serves as a ready and quick method of making the switchgear bus or line available for power take-off or feed. This is possible because the conducting parts of the device are designed to carry 1200 amperes continuously. Also, the test terminals have caps which can be removed to expose a threaded socket suitable for making a heavy current connection. This particular function, or any other function of the grounding and test device, is not limited to 1200-ampere switchgear. Merely by replacing the 1200-ampere primary contact finger assemblies with their 2000-ampere counterparts, the device can also be used in 2000-ampere switchgear.

## Positive grounding is important

While the other functions indicated are convenient and certainly provide an answer to a definite need, perhaps the most important function of the grounding and test device is its day-to-day routine use as a safety device in providing safe and positive grounding of circuits temporarily exposed for repair, maintenance, or other work. When the unit has been locked in place on the circuit to be grounded, the workman is assured of a positively "dead" circuit which will not become ungrounded until he, personally, performs that function.

In use, either of the two grounding combinations shown in Figures 8a and 8b is accomplished by sequential operation of the selector and grounding contacts.

With the device removed from the switchgear cubicle, the selector switch contacts *E* are positioned on either the "bus" or "line" side, depending on the circuit to be grounded. The setting may be checked by the "line-bus" indicator on the front of the device or by visual inspection through the transparent plate, which extends over the entire top of the grounding device. When the desired setting has been made, the selector switch handle *D* is removed. This handle is removable only in the full contact positions and must be removed before the unit will fit into the switchgear cubicle, thus assuring that full contact will be made in every case.

The interlock key must be removed from the front interlock *G* and inserted in the rear interlock *B*, then turned to withdraw the bolt, thereby closing an electrical contact in the control circuit. This assures that the front cover *H* over the upper test terminals will be locked in the closed position, prohibiting access to the test terminals which are not used in grounding functions. The lower terminals *J* remain accessible for checking potential prior to establishing the ground. Note that the same terminals are used for potential check before grounding either line or bus side, thereby removing any chance of confusion or human error in this operation.

The elevating gear interlock *L* must be in the "inboard" position to permit insertion of the device into the cubicle. This is an additional check that the grounding contacts are open, since interlock *L* is blocked in the "outboard" position and cannot be moved when the grounding contacts are closed. In the inboard position, interlock *L* opens an electrical contact in the control circuit, thereby preventing operation of the solenoid mechanism which actuates the grounding contact blades.

When the desired setting of the selector switch has been made and proper positions of the interlocks established, the device may be inserted into the switchgear cubicle and elevated into position. However, before the circuit can be grounded, it is necessary to remove the crank used in elevating the device and to move interlock *L* into its "outboard" position. This does two things: first, it covers the socket for the elevating mechanism crank, thereby preventing lowering of the device; and second, it closes another electrical contact in the control circuit. Once the grounding contacts have been closed, interlock *L* cannot be moved, and lowering of device in cell is thereby prevented.

## Grounding remotely controlled

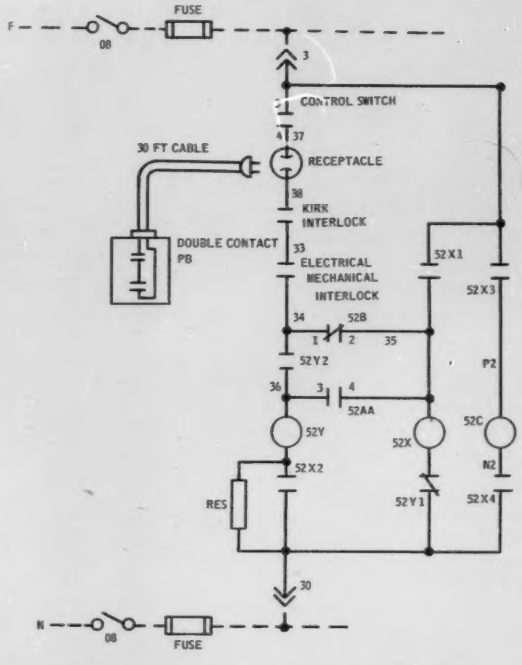
Once the unit has been positioned in the cubicle and the elevating mechanism interlock properly set, it is only necessary to close the grounding contacts to positively ground the desired circuit. Closing of the grounding contacts is accomplished electrically by means of a remotely controlled solenoid operator. The final step before operation of the grounding contact blades is to turn the control switch handle to the "close" position. This action establishes a final electrical contact in the series of interlocks and locks the solenoid operator in a non-trip-free position. Thus a closing operation, once initiated, will be carried to completion, and the grounding contacts will remain in the closed position until the operator desires to open them. Thus there is no possibility of the contacts opening and drawing an arc.

The pushbutton station which is used to energize the solenoid mechanism is a two-button station having both normally open contacts wired in series. Both buttons must be pushed simultaneously to establish the electrical circuit. This procedure prevents accidental operation of the grounding contact blades, since both hands are required to close the two contacts in the pushbutton station. The pushbutton station is mounted at the end of a fifty-foot control cable, thus permitting personnel to remain well clear of the grounding device during the actual grounding of the circuit.

As shown in Figure 9, the electrical control for operation of the grounding contact blades consists of a standard *X-Y* relay scheme, with the addition of various interlocks. The source of power is taken from the switchgear control source through the plugging device provided for the control of a standard breaker.

The desired circuit having been grounded, the operator merely needs to return the control switch handle to its normal or "off" position and remove the handle from the switch in order to lock the grounding device in its grounded position. So long as he retains the control switch handle in his possession, nobody else can trip the device to unground the circuit.

When it is desired to remove the ground from the circuit, the control handle is inserted and turned to the




**CONNECTION DIAGRAM** of grounding device is similar to a standard circuit breaker except that additional interlocks are provided for the safety of personnel. **(FIGURE 9)**

"trip" position, thereby causing the grounding contacts to open and permitting the grounding device to be lowered in the switchgear cubicle and removed if desired. If the line has been grounded and it is desired to change to the grounded bus condition (or vice versa), it may be accomplished by ungrounding the circuit as above and removing the unit from the switchgear to facilitate the necessary change in the selector switch setting. If it is desired to unground a circuit and subsequently re-establish the ground on the same circuit, it is merely necessary to set the control switch and operate the pushbutton as described above, provided no interlocks have been disturbed.

While it once seemed that metal-clad switchgear would not be universally accepted for power generation or distribution systems because it could not be conveniently tested, today it is more convenient, safer and more versatile than the old open-type equipment. New types of grounding and testing devices can be accredited with the general acceptance of metal-clad switchgear. With these new devices the operator can make all the tests that good practice dictates, without delay and without dangerously exposing live bus or cables.


New

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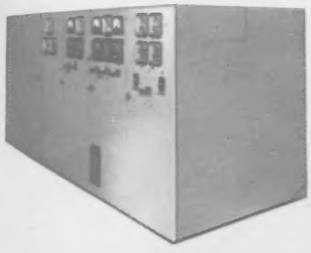
Electrical REVIEW

# COMPLETE
# *Coordinated Electrical Equipment*

## Built for Arc Furnace Duty

**ALLIS-CHALMERS Arc Furnace SUBSTATIONS**

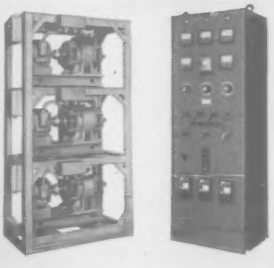


A

**SWITCHING EQUIPMENT** is matched to furnace size and power supply voltage — for a single furnace or a battery of units. Allis-Chalmers switches and breakers are built to withstand the frequent operation required for arc furnace use.

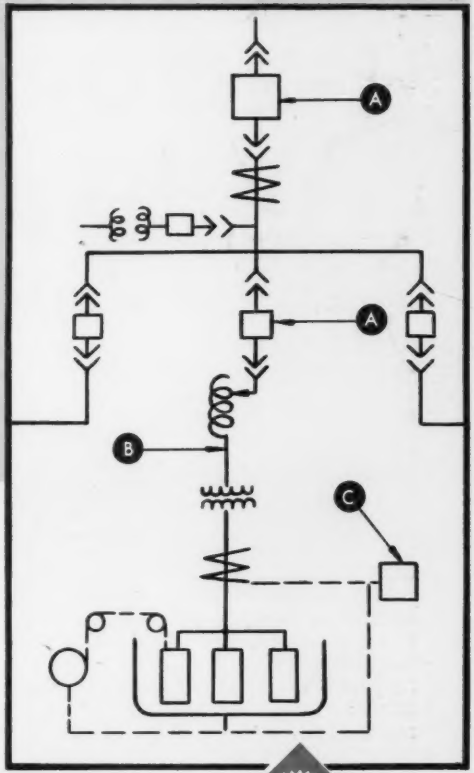
B

**FURNACE TRANSFORMERS** are carefully designed to withstand high current and voltage stresses. They provide built-in reactance and taps for accurate current and voltage control.



C

**CONTROL** consists of *Regulex* rotating amplifier m-g sets and a control and metering panel. Separate m-g sets for each electrode give accurate control. Simple design of *Regulex* sets assures low maintenance costs.




FOR new furnaces or modernization of old ones, Allis-Chalmers can supply electrical equipment designed to fit any furnace builder's requirements. Long a pioneer in arc furnace control equipment, A-C was the first to apply rotating amplifiers, providing accurate arc control, long refractory life, economical power consumption, and minimum maintenance.

For more information, call in your nearby A-C representative, or write to Allis-Chalmers, Milwaukee 1, Wisconsin.

A-3917

*Regulex* is an Allis-Chalmers trademark.

# ALLIS-CHALMERS

A-C ALLIS-CHALMERS

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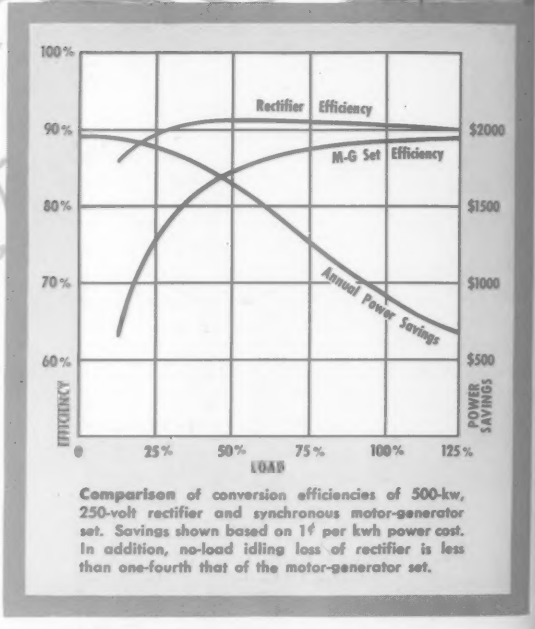
# HERE'S PROOF

## of Low-Loss Conversion

**TO OBTAIN** economical dc power for arc furnace and blooming mill auxiliaries, West Virginia Steel & Manufacturing Company recently installed mercury arc rectifiers.

The factory-packaged Allis-Chalmers unit includes duplicate 500-kw, 250-volt rectifiers, with tube, breaker, control, and metering compartments, plus dc and ac plant feeder breakers. Since transformers could be installed outdoors, the assembly departs from the usual double-ended arrangement.

Rectifiers were chosen for their high conversion efficiencies *plus* simplified foundation needs, easy installation and minimum maintenance. And Allis-Chalmers units incorporate continuous excitation, grid phase control, internal cooling and enameled anode seals.




Comparison of conversion efficiencies of 500-kw, 250-volt rectifier and synchronous motor-generator set. Savings shown based on 1¢ per kwh power cost. In addition, no-load idling loss of rectifier is less than one-fourth that of the motor-generator set.

**Use A-C's Engineering Experience**

By calling your A-C representative, you can put A-C's quarter century of rectifier application experience to work on your power conversion problems. Allis-Chalmers, Milwaukee 1, Wisconsin. A-3989

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